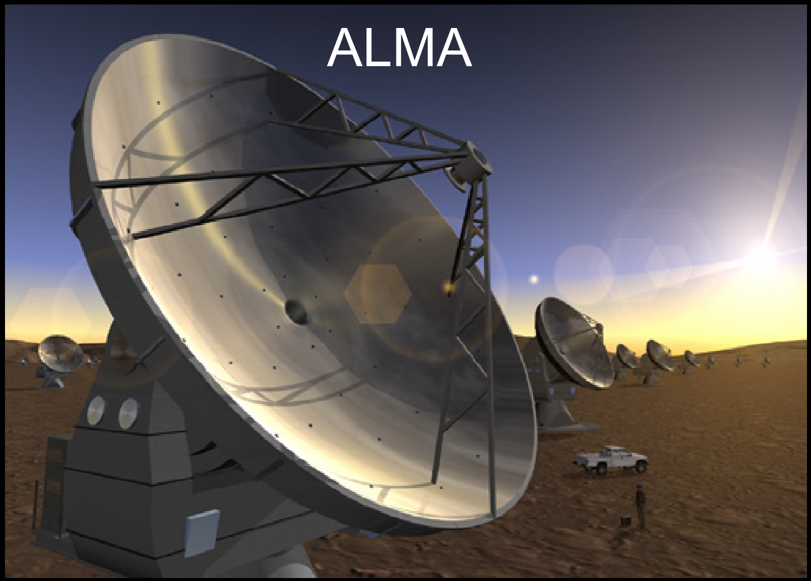
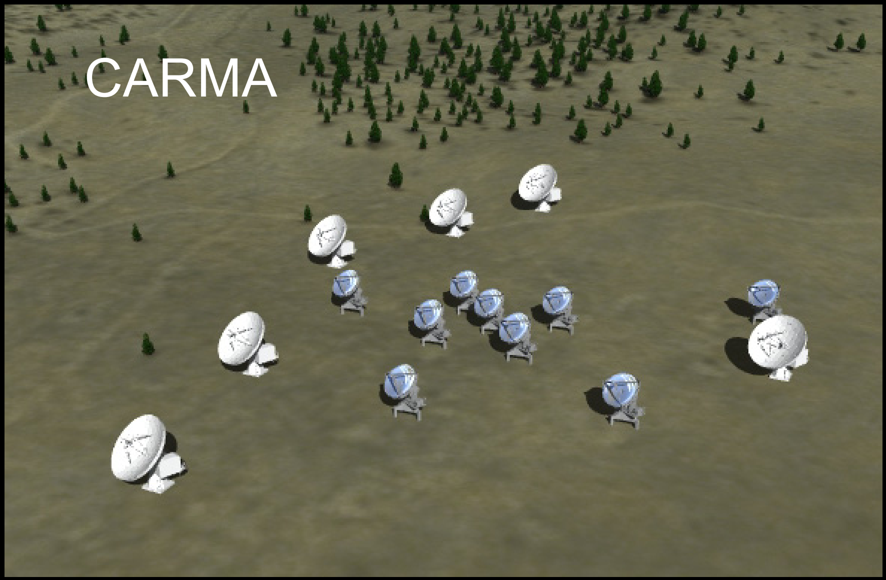
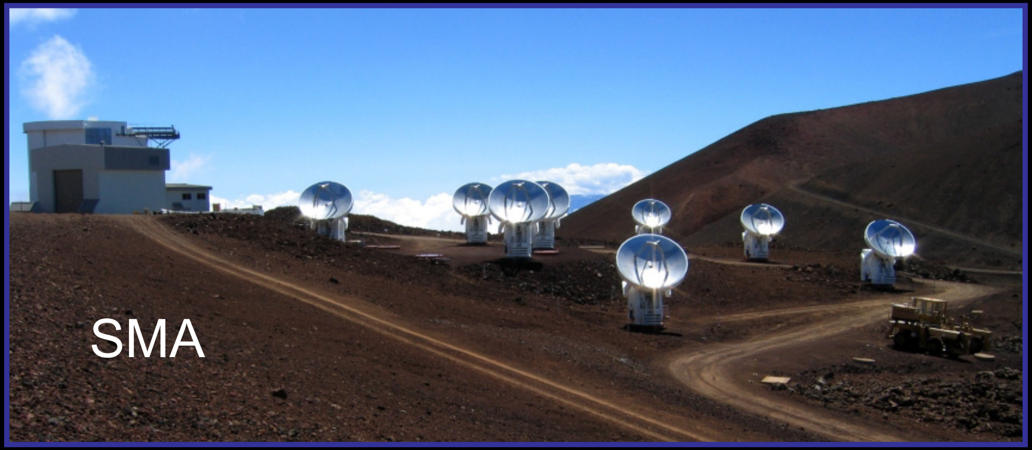




Interferometric Arrays During Spitzer and Beyond



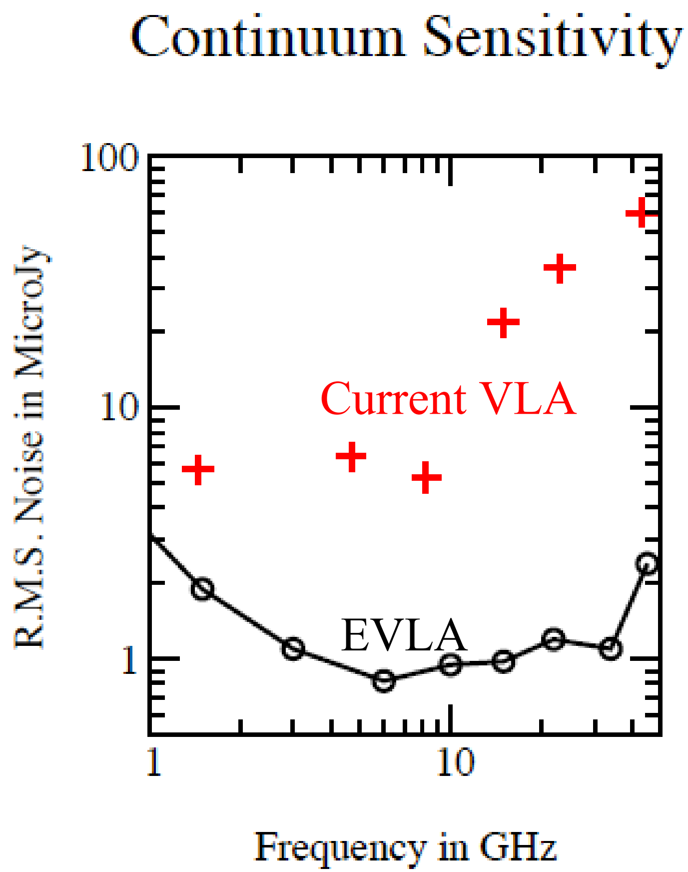
Lee Mundy, University of Maryland

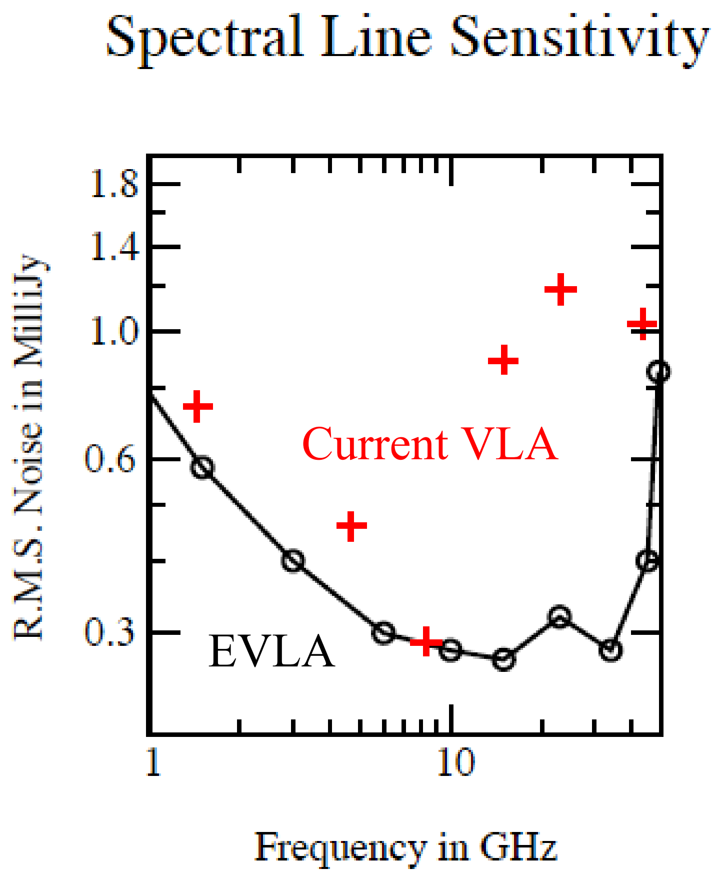
EVLA – An Upgrade to the VLA

- frequency: 1 - 50 GHz
- sensitivity: 1 μJy in 12 hours
- resolution: 10 masec @ 20 GHz (Phase II)
- brightness sensitivity: 0.1 mK @ 10 GHz @ 10"
- new correlator:
  - 16384 channels at full bandwidth,
  - 4.2M channels at highest spectral resolution;

More sensitive, higher resolution,
better frequency coverage, better correlator

EVLA Sensitivity





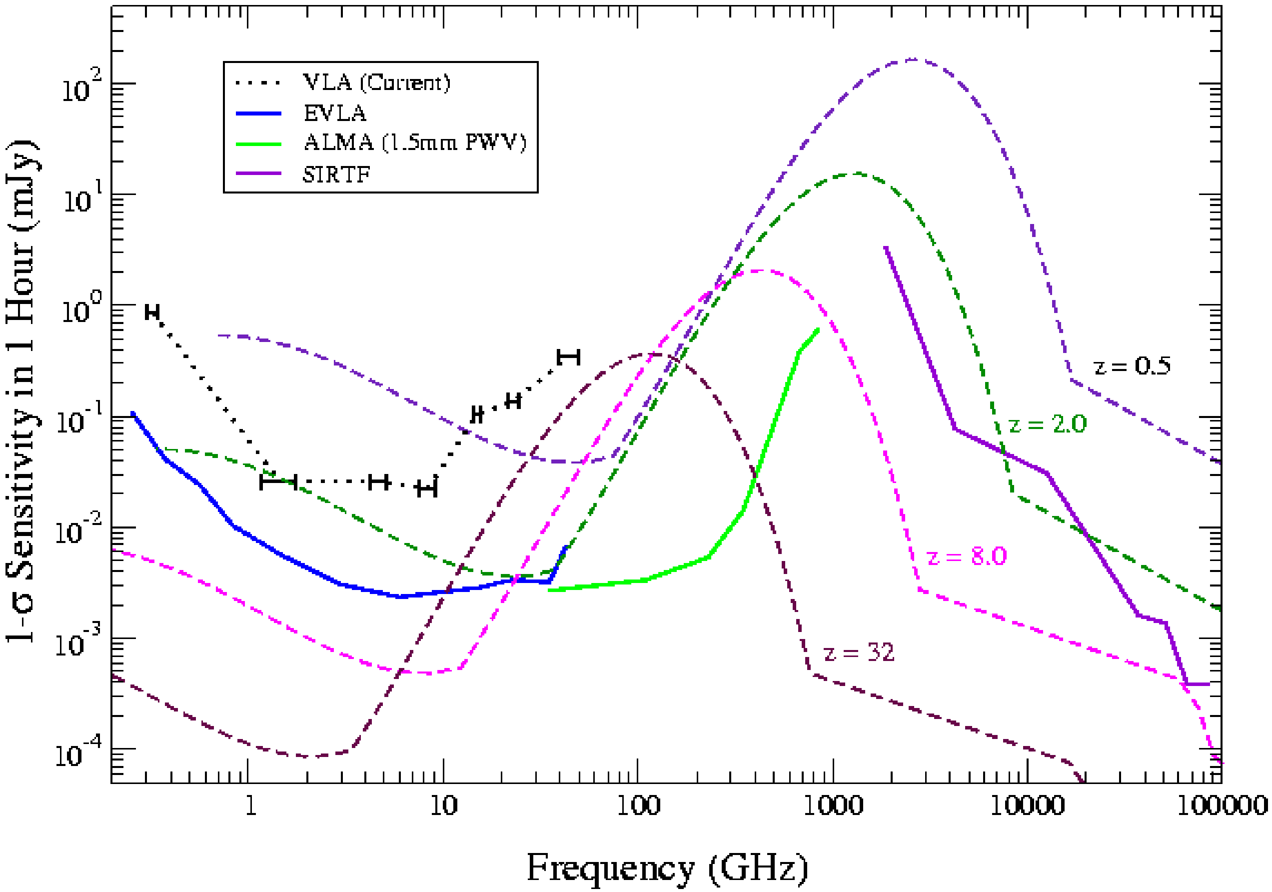
Factors of 20 to 50 better at high frequencies in the continuum

Phased Deployment

Phase I - hardware, electronics, correlator, and software
currently funded at $5M/year for completion in 2012

Phase II - 8 new antennas, 20 new close-packed pads
proposal just went in to NSF. Could also be completed by 2012 if funded soon.

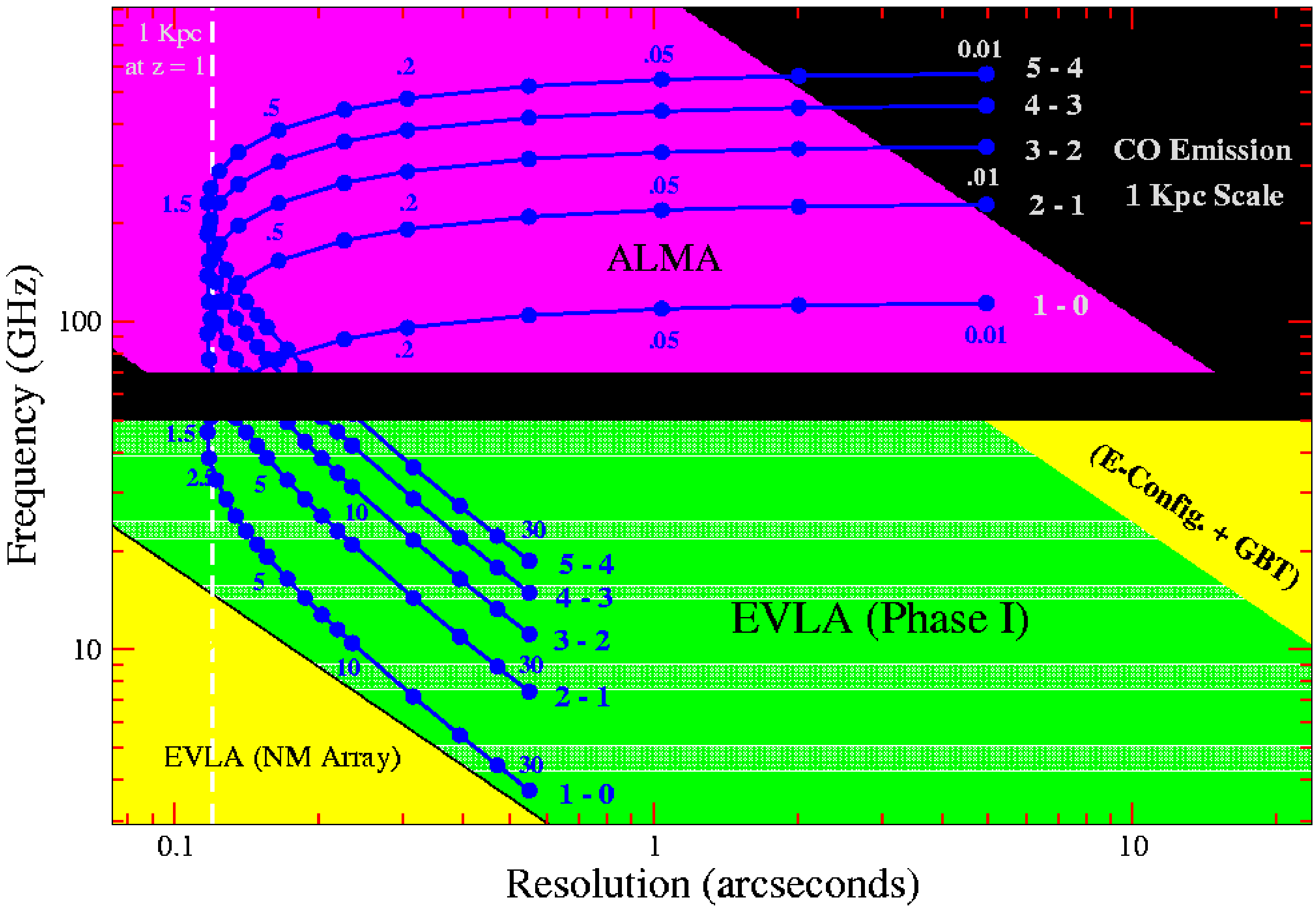
Why improve the VLA ?



- Non-thermal processes emit at cm-wavelengths
- Lower dust opacity at long λ
- Cosmic expansion shifts spectrum to longer λ

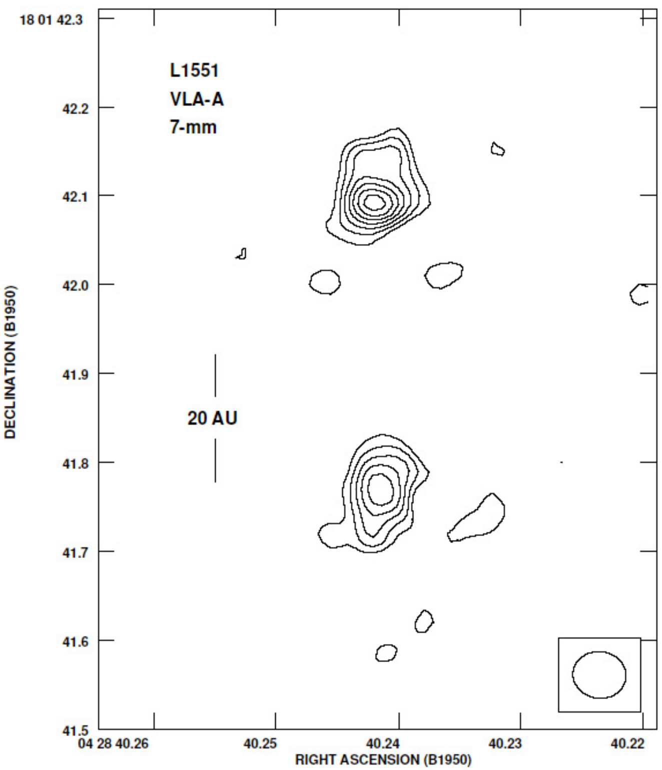
Resolving CO Throughout the Universe

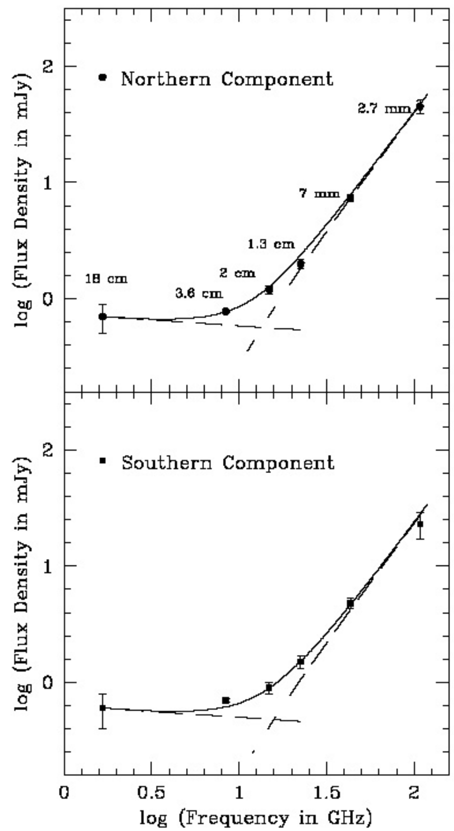
An Example of ALMA-EVLA Synergy



At z > 1.5 the low J CO lines shift into the EVLA bands

Why both EVLA and ALMA?





- The inner disks are optically thick at mm λ
- cm and mm emission can trace difference physical processes: winds, shocks and ionized gas versus dust
- Coordinated attack on inner disk and wind

CARMA

Combined Array for Research in Millimeter-Wave Astronomy

Combined Array for Research in Millimeter Astronomy

Caltech Six 10.4 m dishes

Berkeley – Illinois – Maryland
Nine 6.1 m dishes

Chicago
Eight 3.5 m dishes


New CARMA Site
Inyo National Forest
Cedar Flat – 7300’

CARMA D Array + SZA

CARMA Sensitivity

Line:
1 km/sec

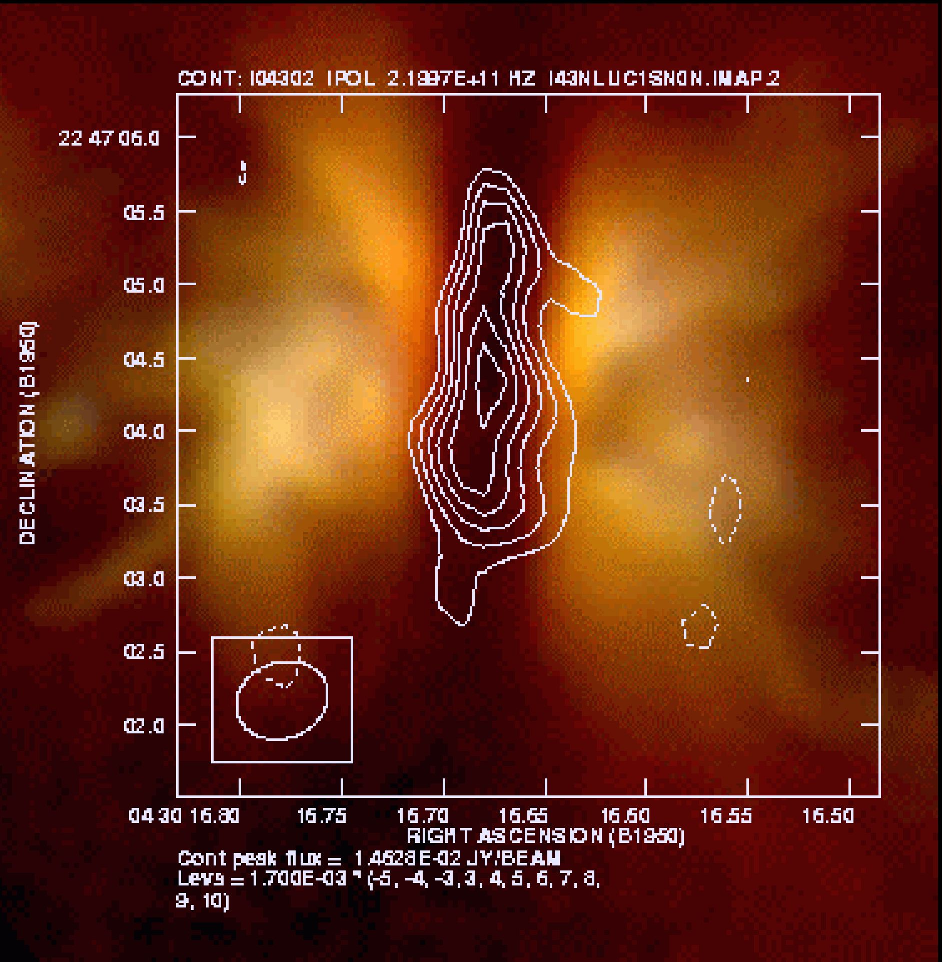
Array	100 GHz			230 GHz		
	Beam	1-min	5-hr	Beam	1-min	5-hr
D	6.3”	0.3 K	0.02 K	2.7”	0.4 K	0.02 K
C	2.5”	2.0 K	0.1 K	1.1”	2.2 K	0.13 K
B	1.0”	12 K	0.7 K	0.4”	17 K	1.0 K
A	0.4”	77 K	4.5 K	0.2”	67 K	4 K

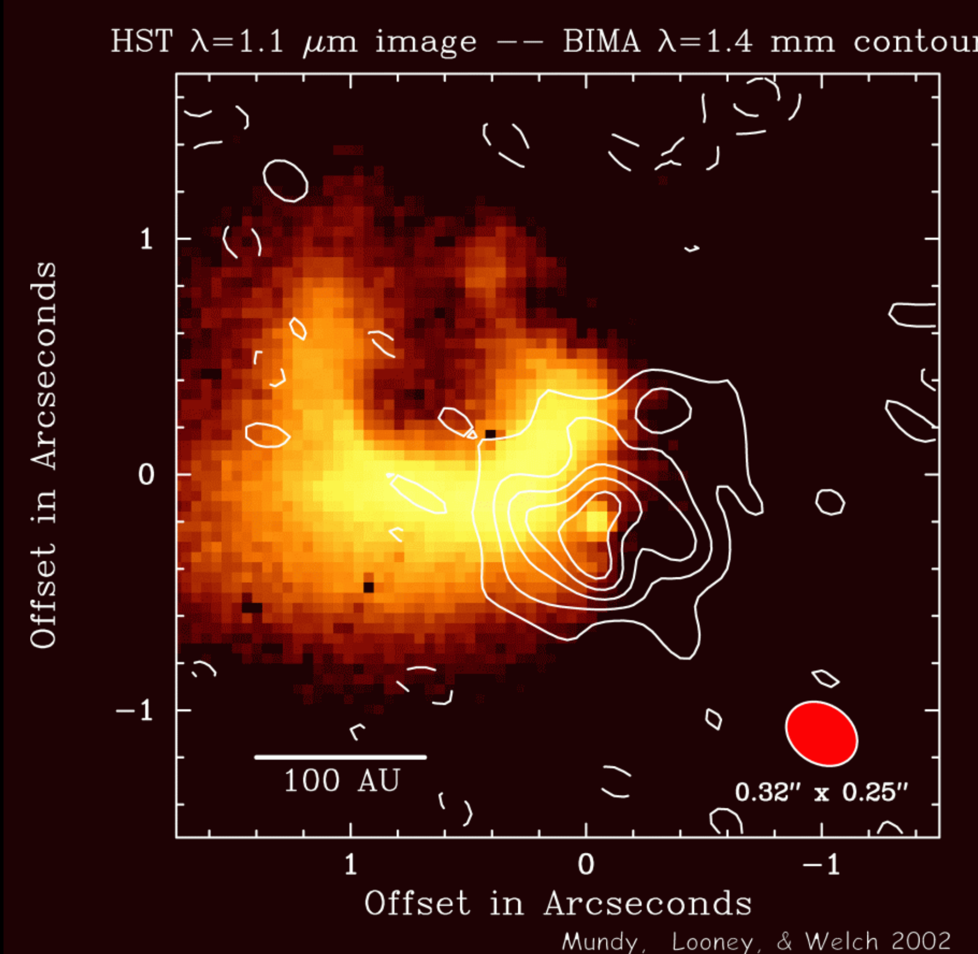
Continuum

100 GHz		230 GHz	
1-min	5-hr	1-min	5-hr
0.7 mJy	0.04 mJy	1.1 mJy	0.07 mJy

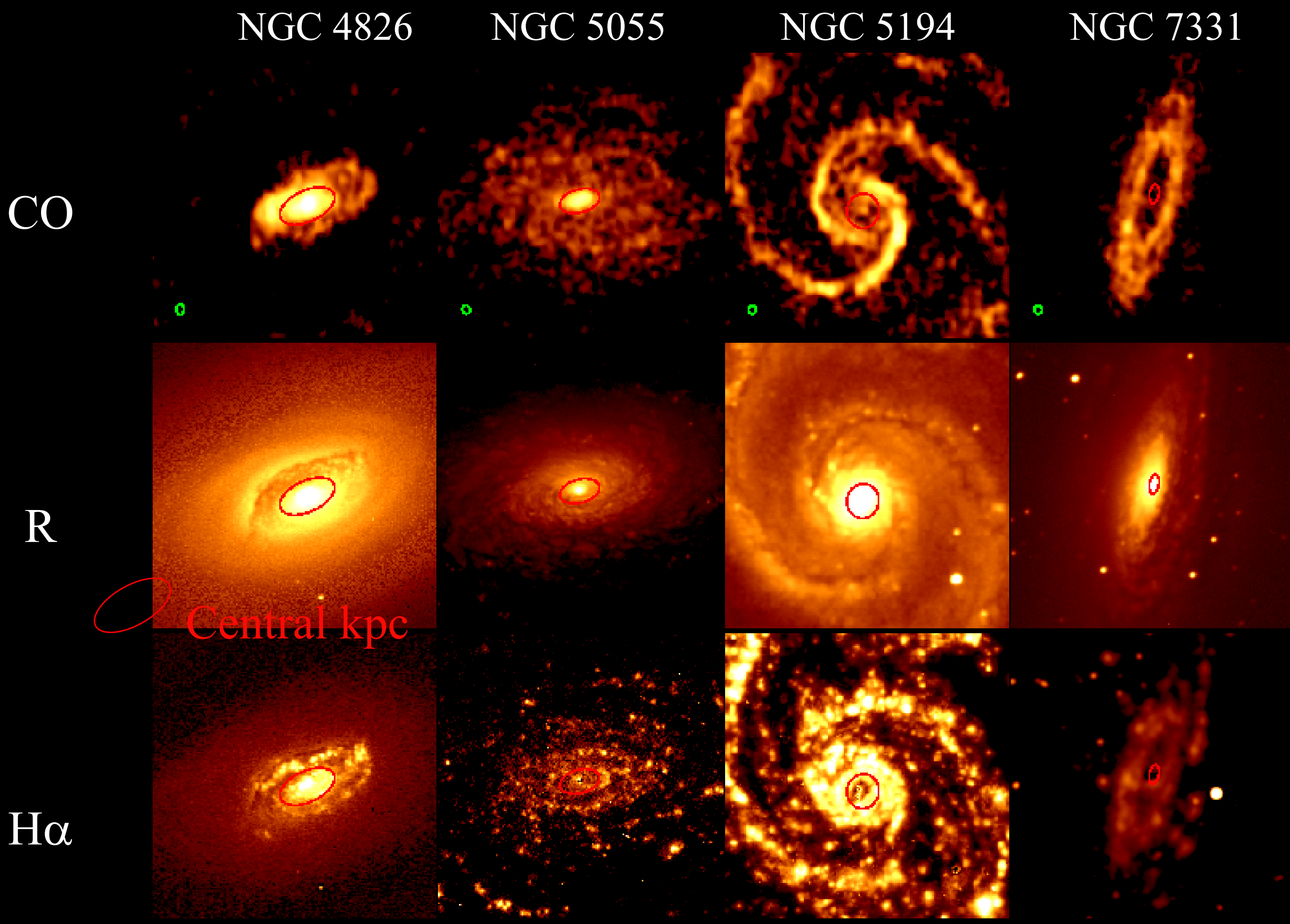
Factor of 5 to 20 better than BIMA/OVRO Arrays

High resolution
High sensitivity





2 km baselines – 0.12” @1mm



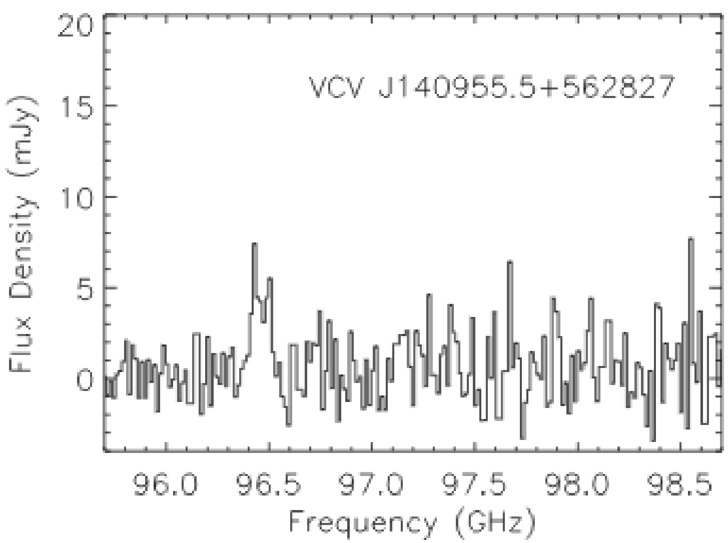
Unbarred galaxies in BIMA SONG Survey

Large bandwidth, high sensitivity

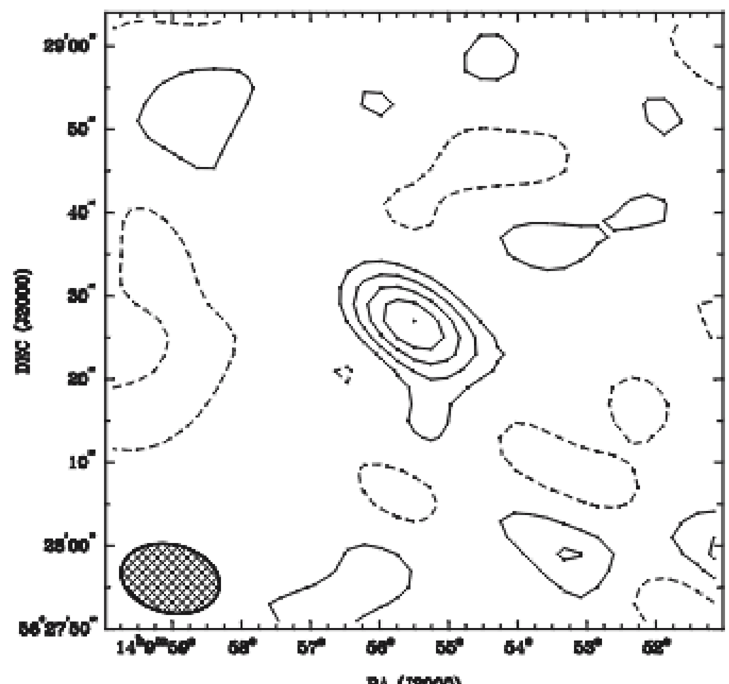
CARMA

Combined Array for Research in Millimeter-Wave Astronomy

J1409 high redshift (z=2.59) quasar detection and map



Data courtesy Nick Scoville, Min Yun, and Laura Hainline.



Map of integrated CO emission in J140955.5+562827. The contours are multiples (-1,1,2,3,4,5) of the rms noise level, which is 0.49 Jy beam^{-1} km s^{-1}.

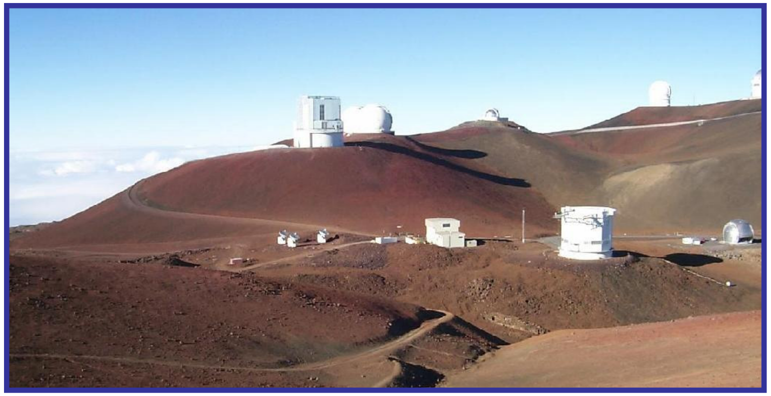
CARMA
Combined Array for Research in Millimeter-Wave Astronomy

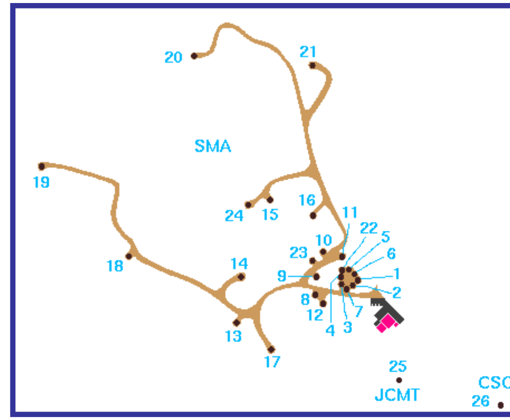
Timeline

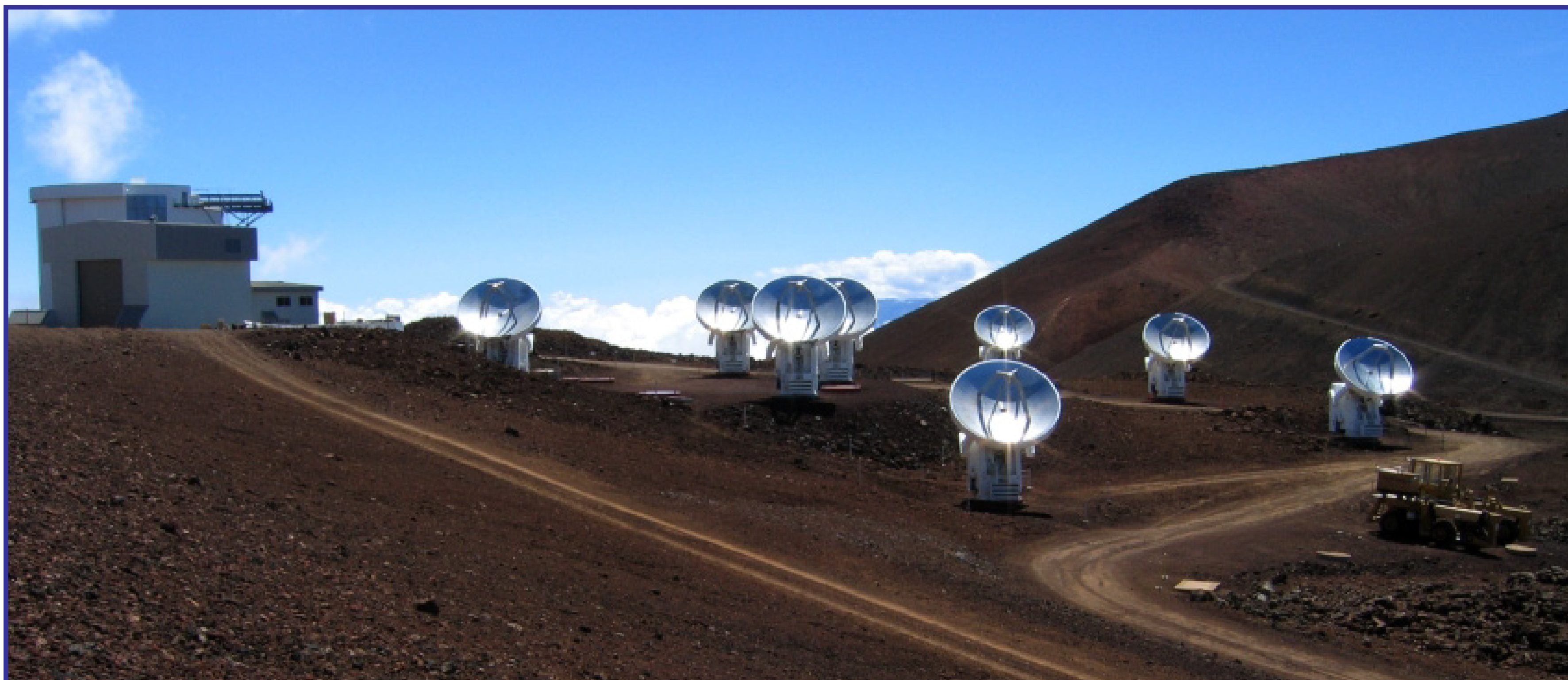
• Cedar Flat permit	*2003 December*
• Shut down BIMA & OVRO	*2004 June*
• Roads, pads, buildings	*2004 Summer*
• Move BIMA & OVRO	*2004 Fall*
• First light & Operations	*2005 Fall*

The SubMillimeter Array on Mauna Kea

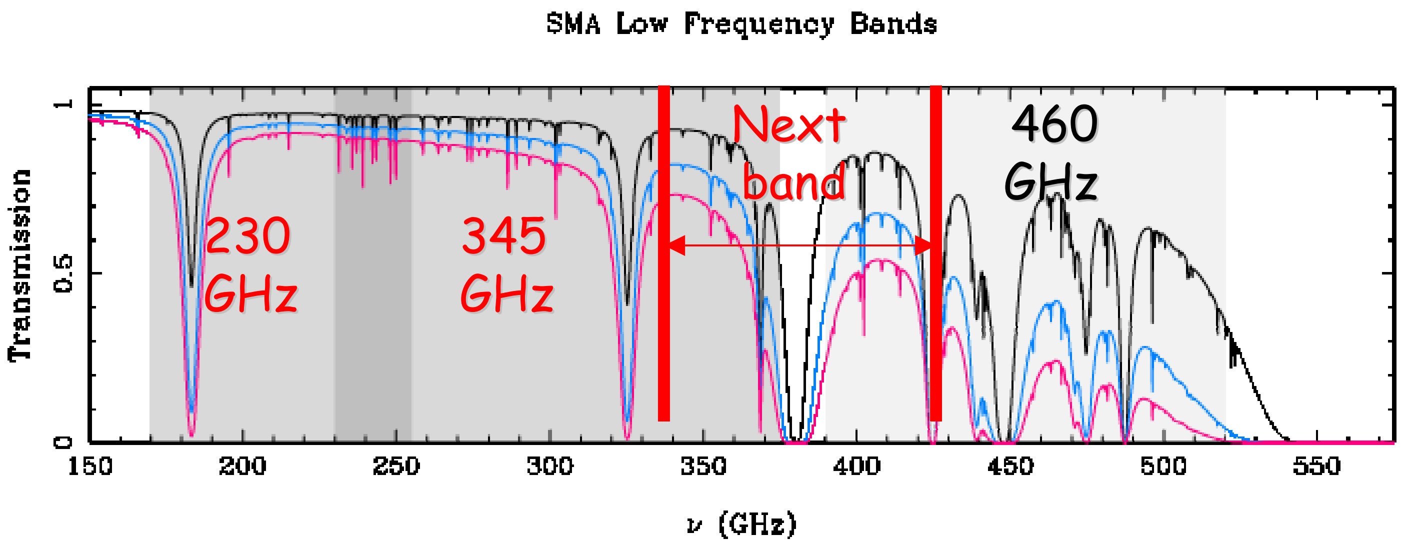
SAO and ASIAA

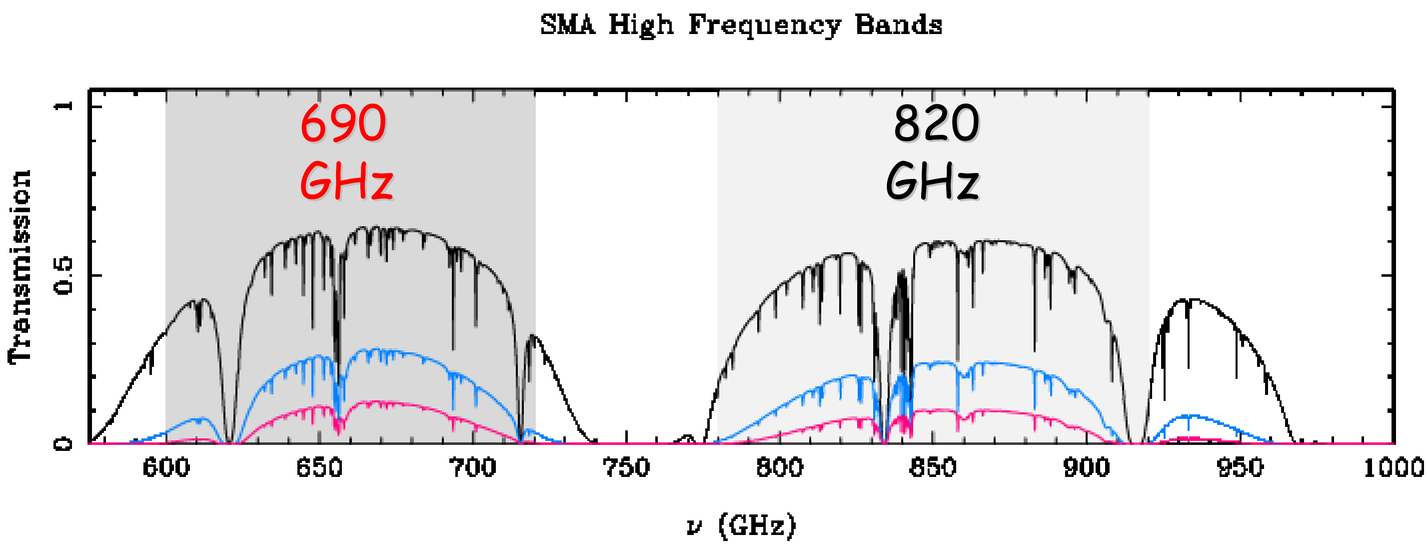


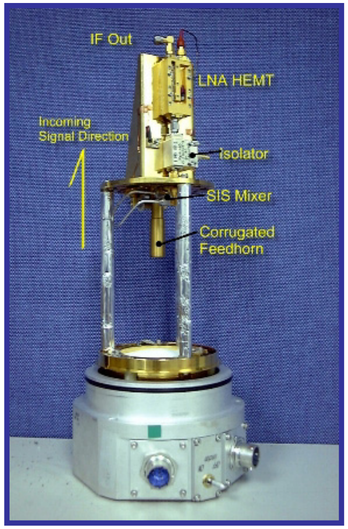




SMA Receiver Bands



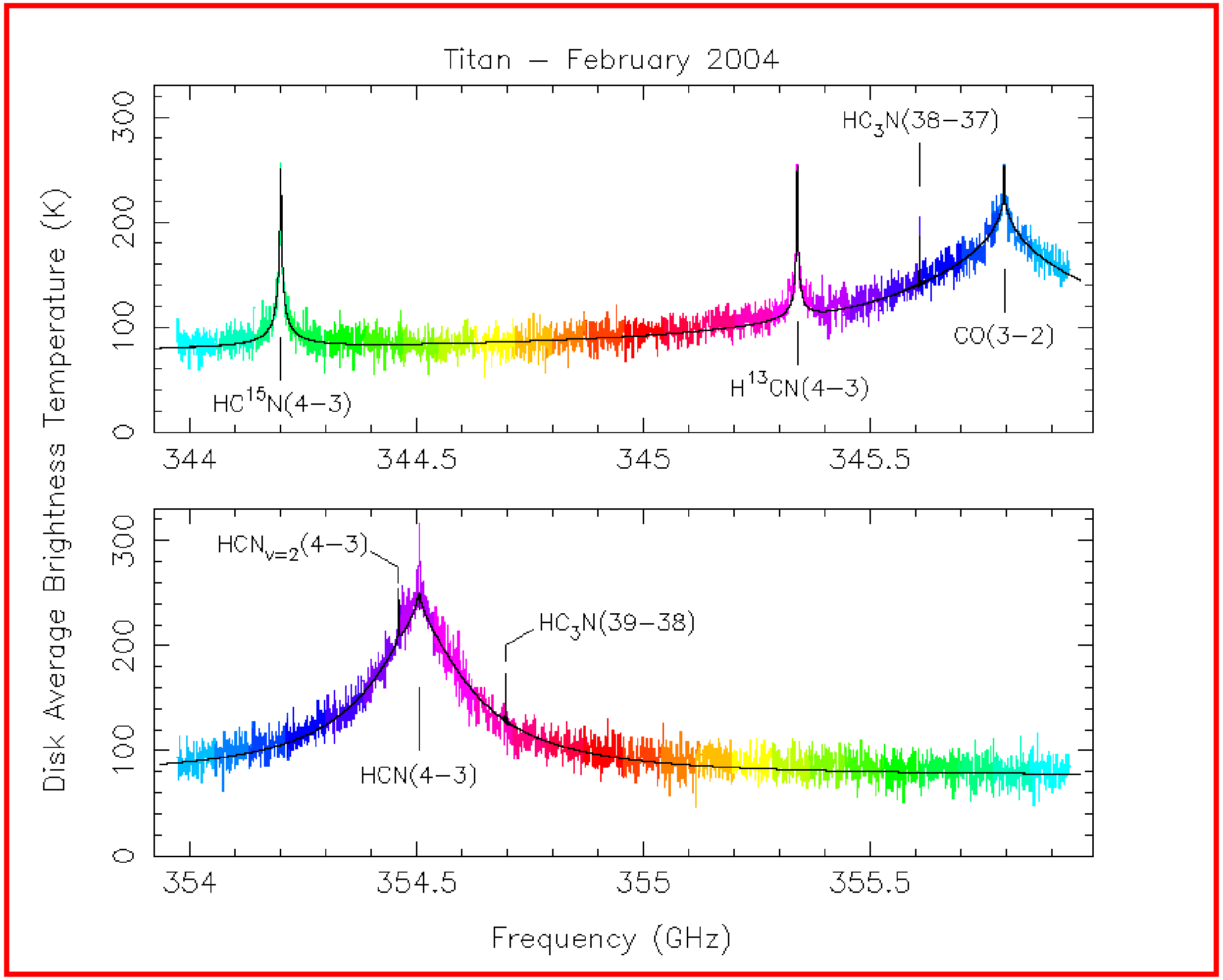




Solar System: Titan

Titan Atmosphere is Rich in Different Molecular Species

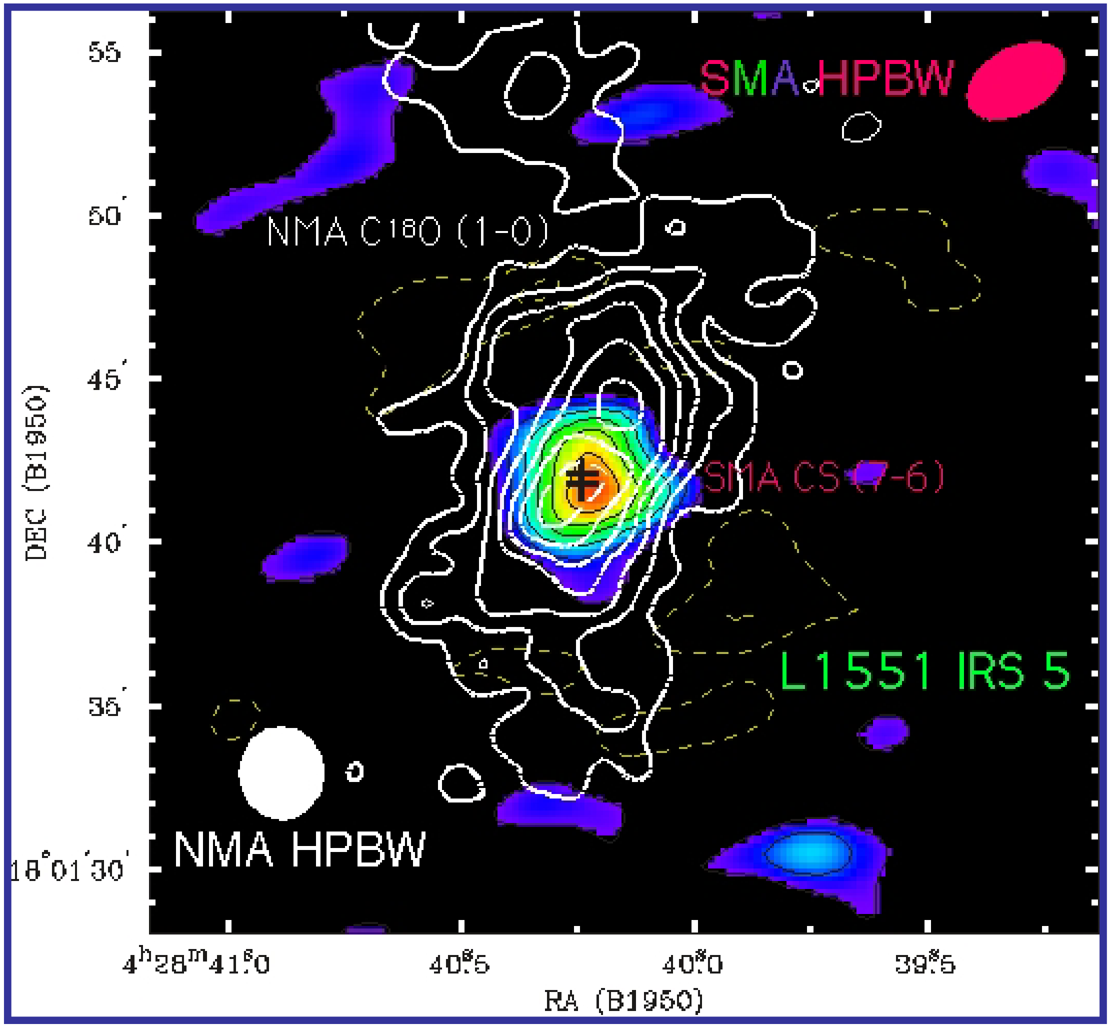
M. Gurwell



Young Star: L1551 Gas Image

Submm Line Picks up Warm Dense Core Within Cooler Envelope

(> 60 K) (> $10^7 cm^{-3}$) (700 AU)



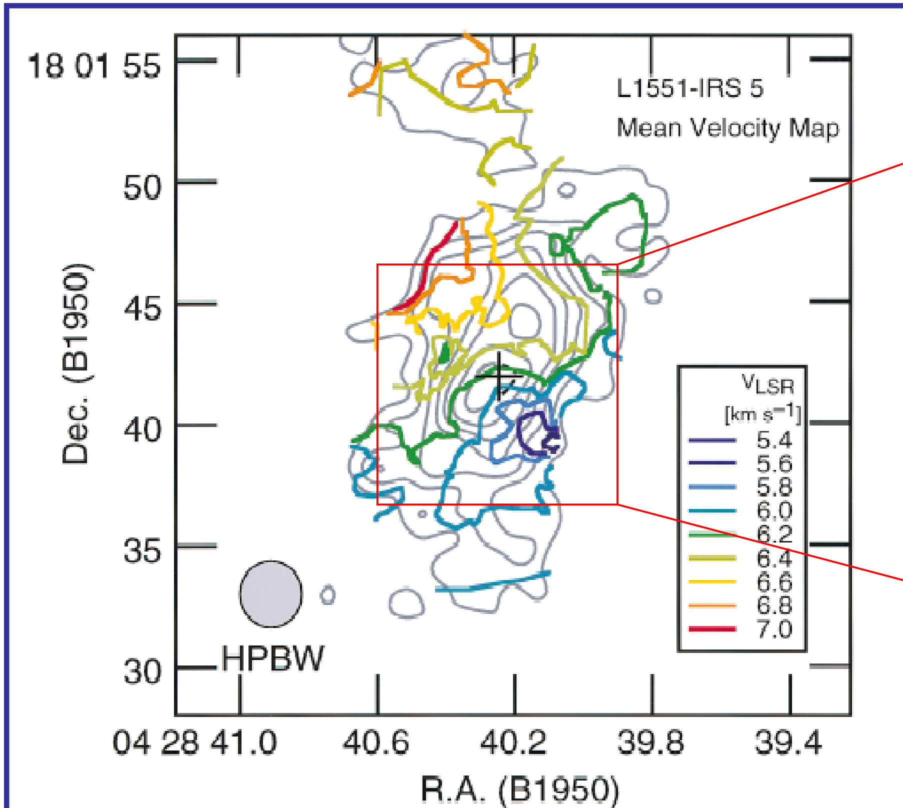
CS 7-6

S. Takakuwa

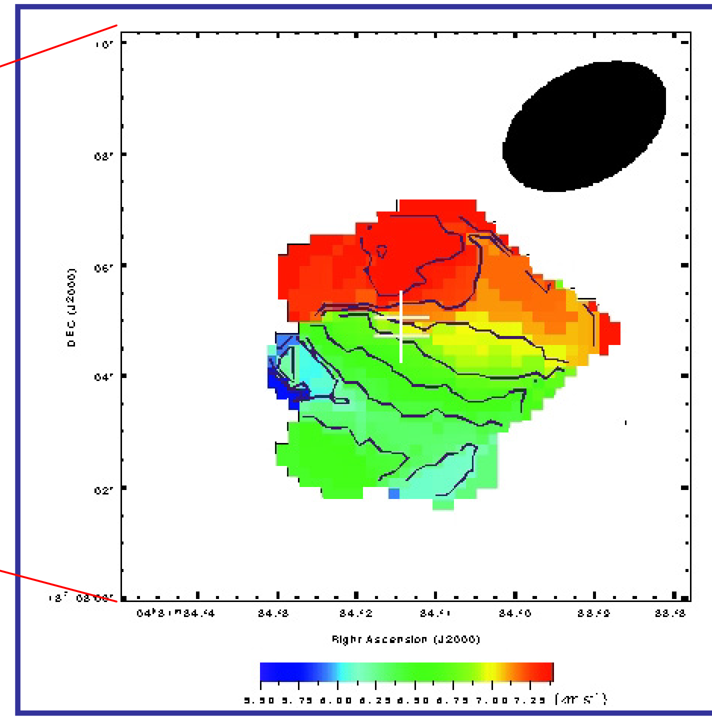
Circumbinary Disk ?

Gas Shows Rotational Motions

$C^{18}O$ (1-0)



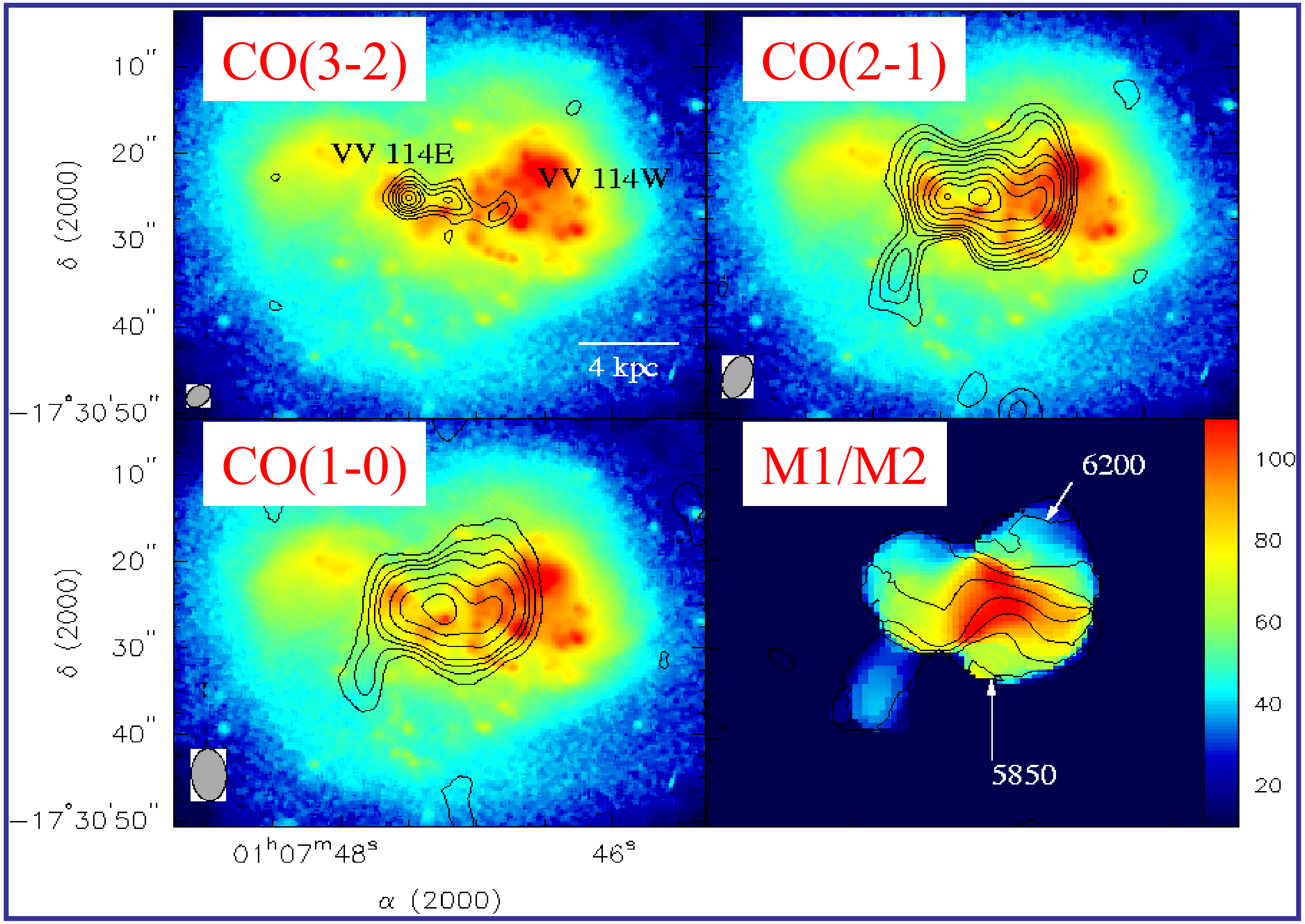
CS (7-6)



Motion Dominated by Kepler Rotation at 100 AU Scale

Interacting System VV114

CO J=2-1 very similar to J=1-0; CO J=3-2 picks out Hot Core



D = 77 Mpc

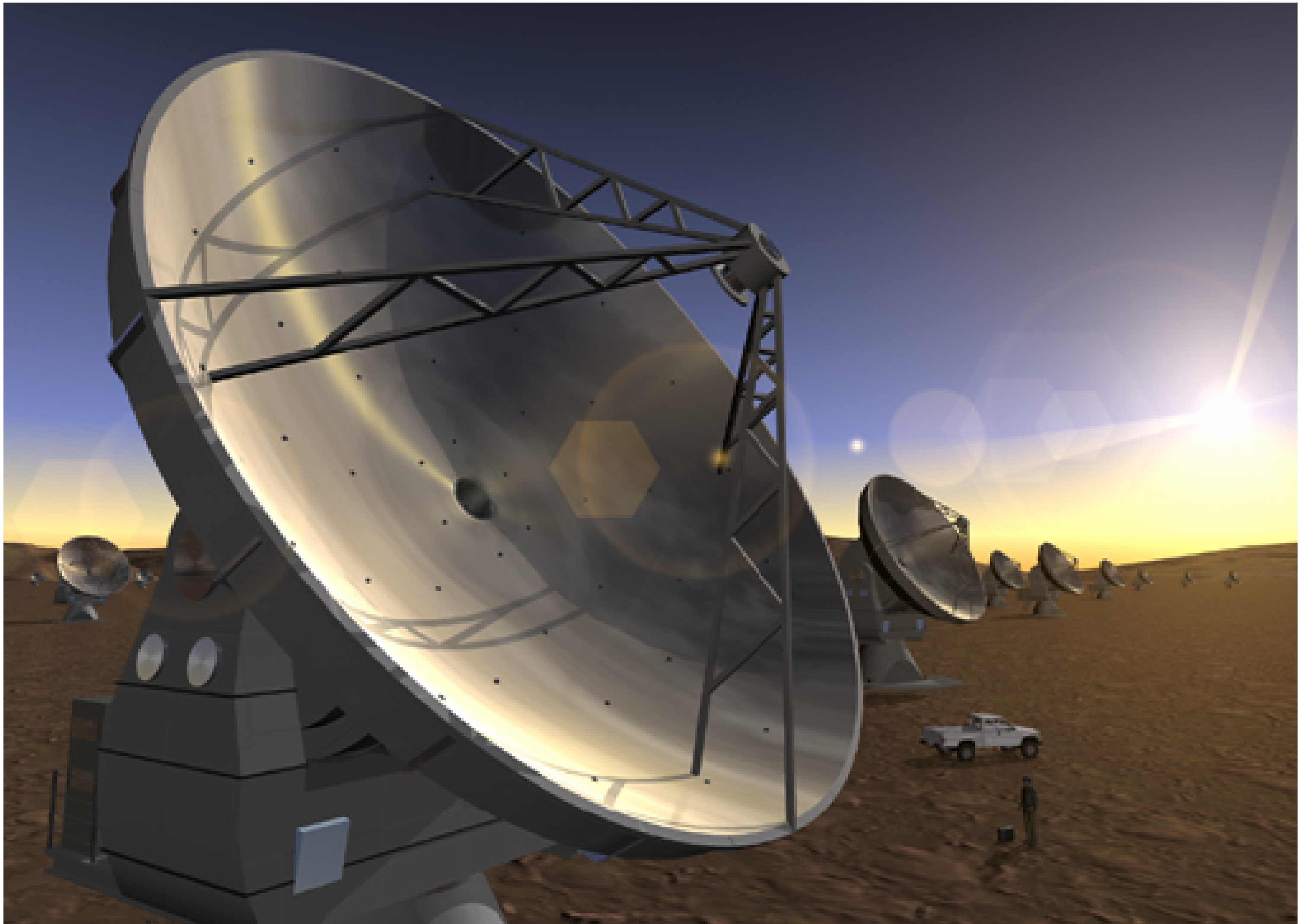
L_{IR} = 4.0 x 10^{11} L_{sun}

M_{H2} = 5.1 x 10^{10} M_{sun}

Late stage merger

D. Iono

ALMA Atacama Large Millimeter Array



ALMA

ALMA is an equal partnership between Europe and North America, in cooperation with the Republic of Chile, and is funded by:

- the U.S. National Science Foundation (NSF),
- the National Research Council of Canada (NRC),
- the European Southern Observatory (ESO), and Spain.

ALMA construction and operations are led on behalf of Europe by **ESO**, and on behalf of North America by the National Radio Astronomy Observatory (**NRAO**), which is managed by Associated Universities, Inc. (**AUI**).

ALMA Scope

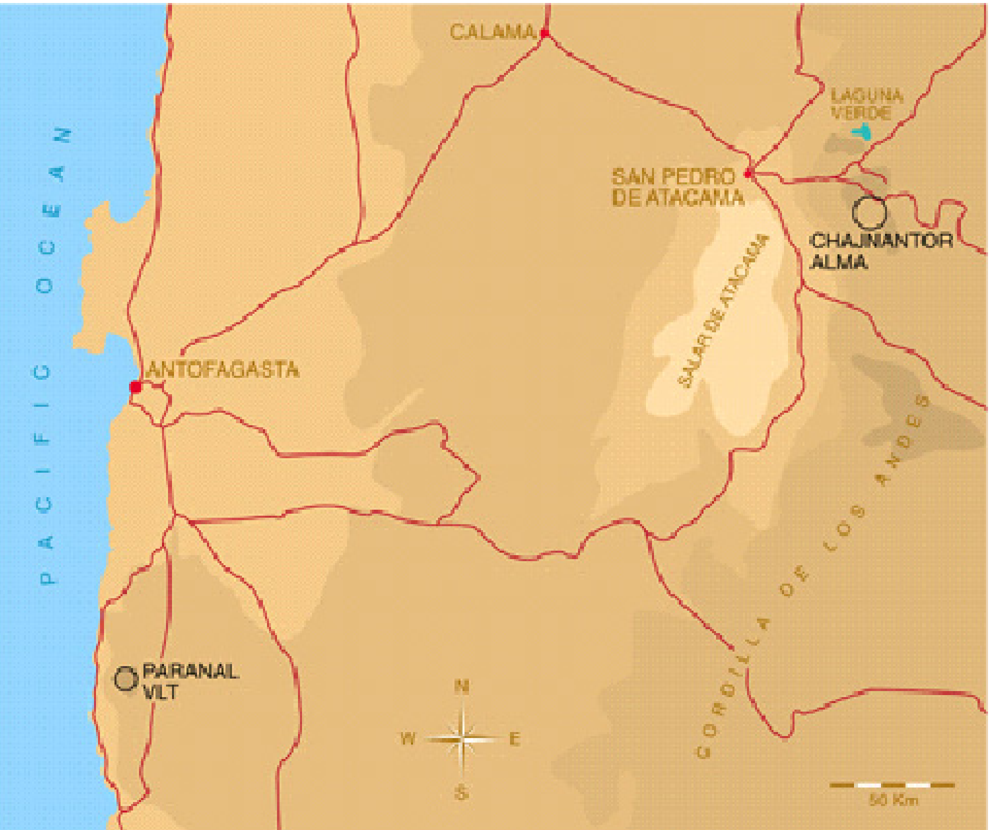
Antennae	64 × 12 m
collecting area	> 7000 m^2
Configurations	150 m – 14 km
resolution (300 GHz)	1.4 – 0.015"
Frequency	31 – 950 GHz
wavelength	10 – 0.3 mm
Receiver sensitivity	close to quantum limit
Correlator	16 GHz / 4096 chan.
Site	excellent
Total Cost (FY2000 $)	562M USD

A leap of *over two orders of magnitude in both spatial resolution and sensitivity*

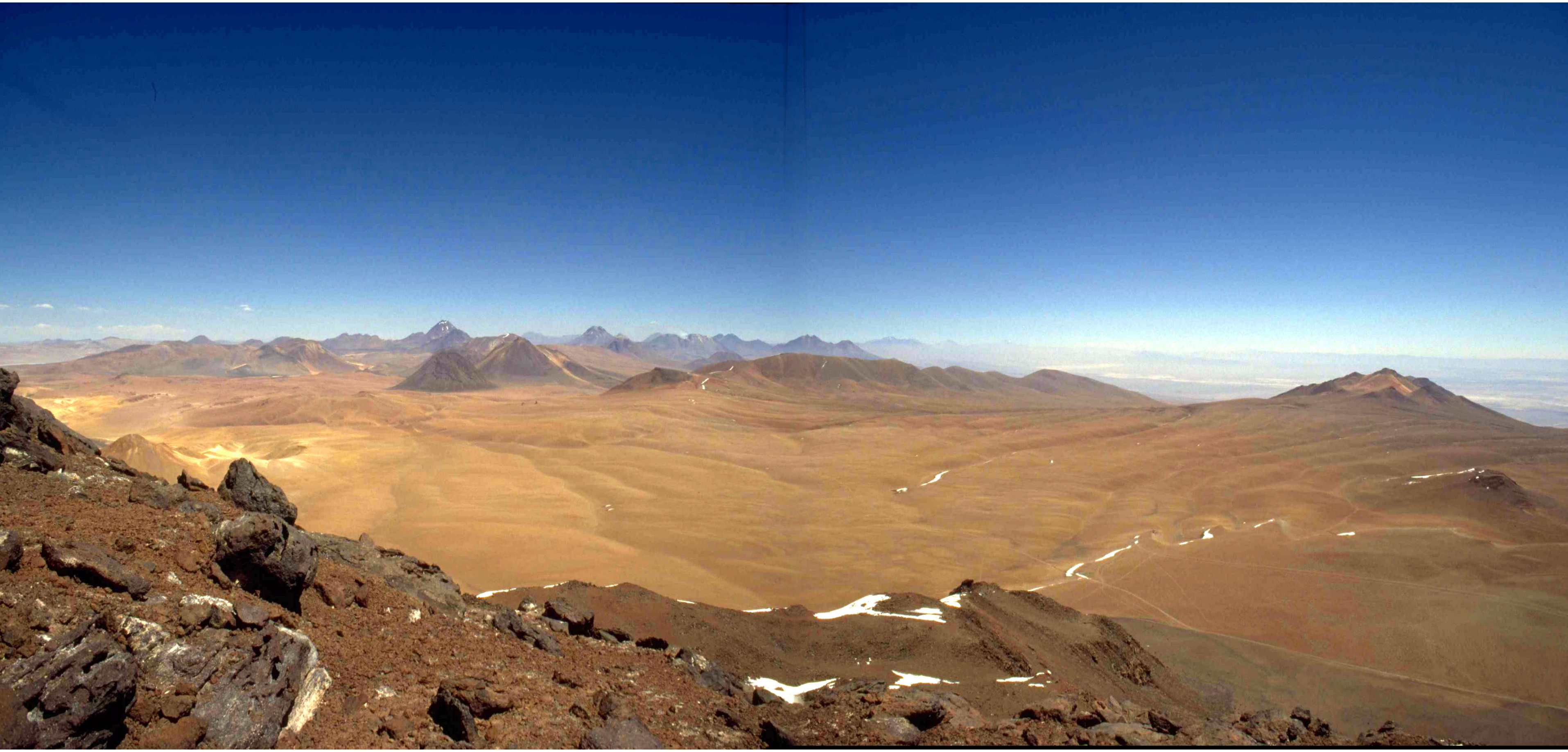
Site in Northern Chile

High Atacama Desert:

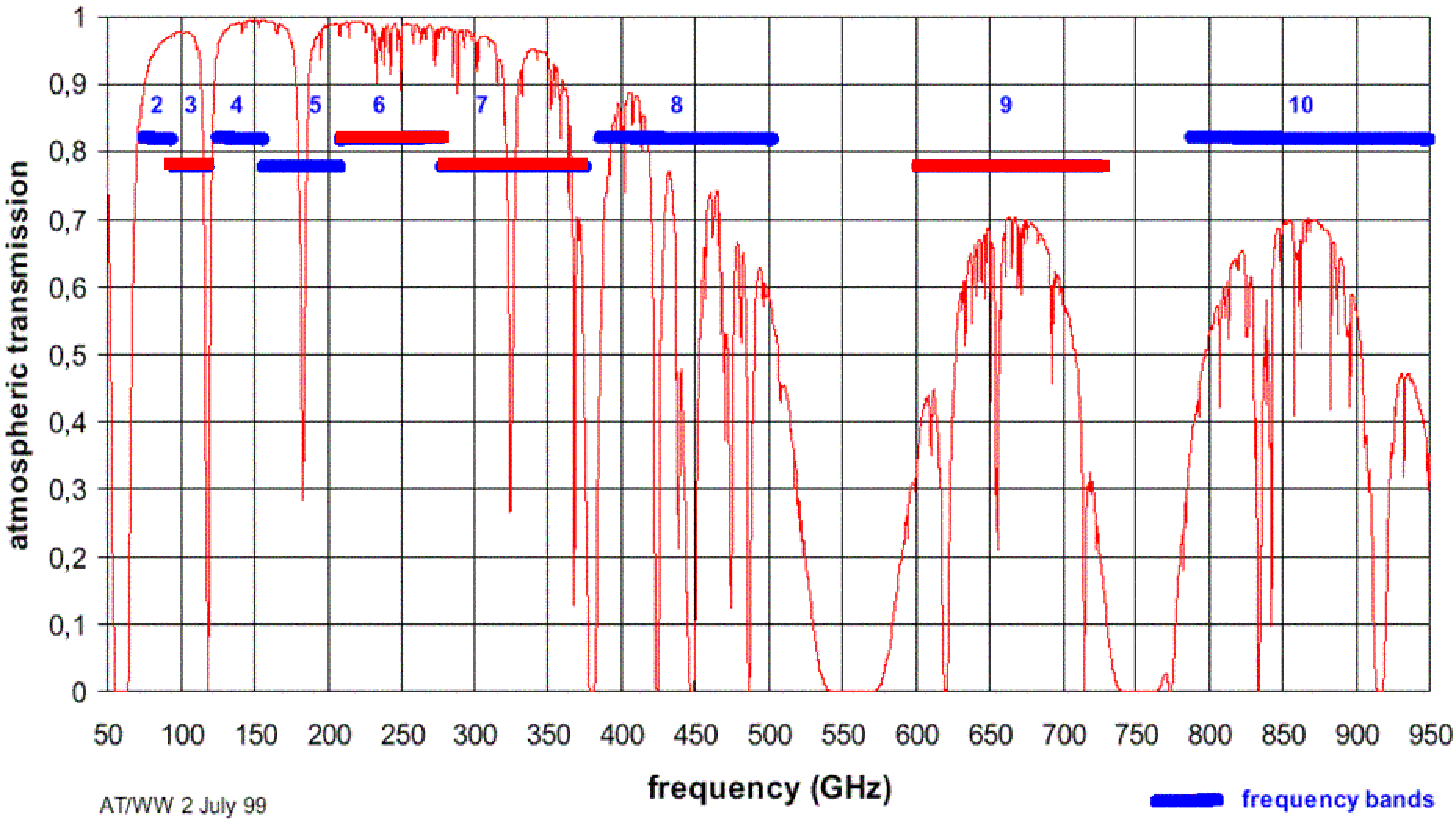
low water vapor, moderate climate, good access



ALMA Site:Chajnantor



Atmospheric transmission at Chajnantor, pwv = 0.5 mm



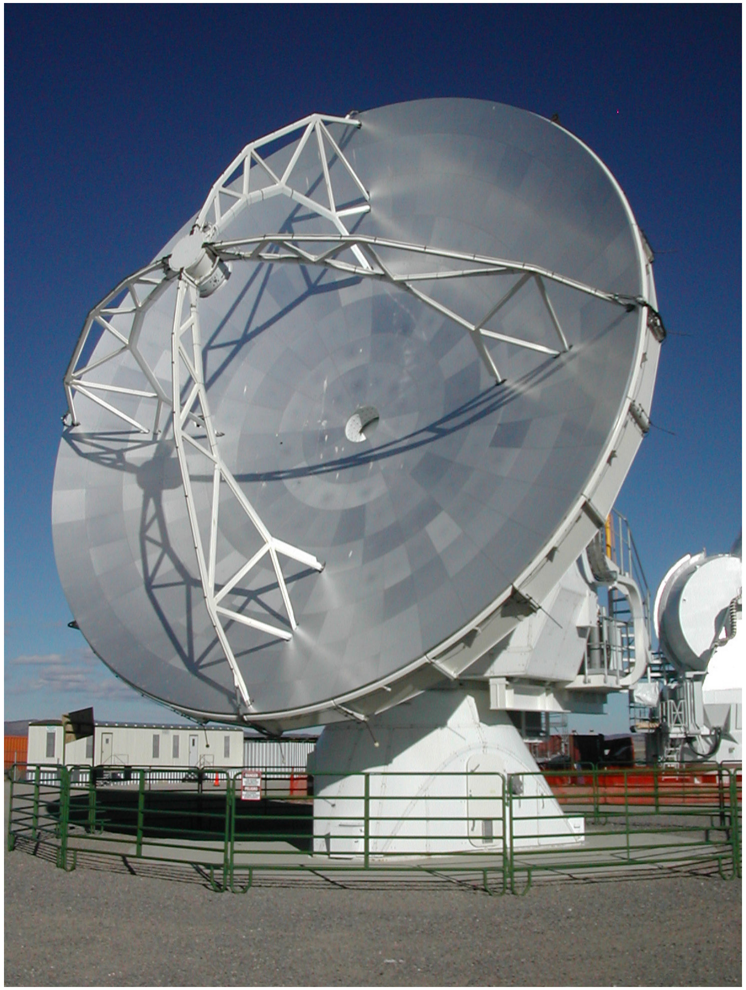
ALMA FE key specifications

ALMA Band	Frequency Range	Receiver noise temperature / SSB		Receiver noise temperature / DSB		Receiver technology
		T_{SSB} over 80% of the RF band	T_{SSB} at any RF frequency	T_{DSB} over 80% of the RF band	T_{DSB} at any RF frequency	
1	31.3 – 45 GHz	15 K	23 K	8 K	12 K	HEMT
2	67 – 90 GHz	28 K	43 K	14 K	22 K	HEMT
3	84 – 116 GHz	34 K	54 K	17 K	27 K	SIS
4	125 – 163 GHz	47 K	76 K	24 K	38 K	SIS
5	163 - 211 GHz	60 K	98 K	30 K	49 K	SIS
6	211 – 275 GHz	77 K	126 K	39 K	63 K	SIS
7	275 – 370 GHz	133 K	198 K	67 K	99 K	SIS
8	385 – 500 GHz	181 K	270 K	91 K	135 K	SIS
9	602 – 720 GHz	335 K	500 K	168 K	250 K	SIS
10	787 – 950 GHz	438 K	655 K	219 K	328 K	SIS

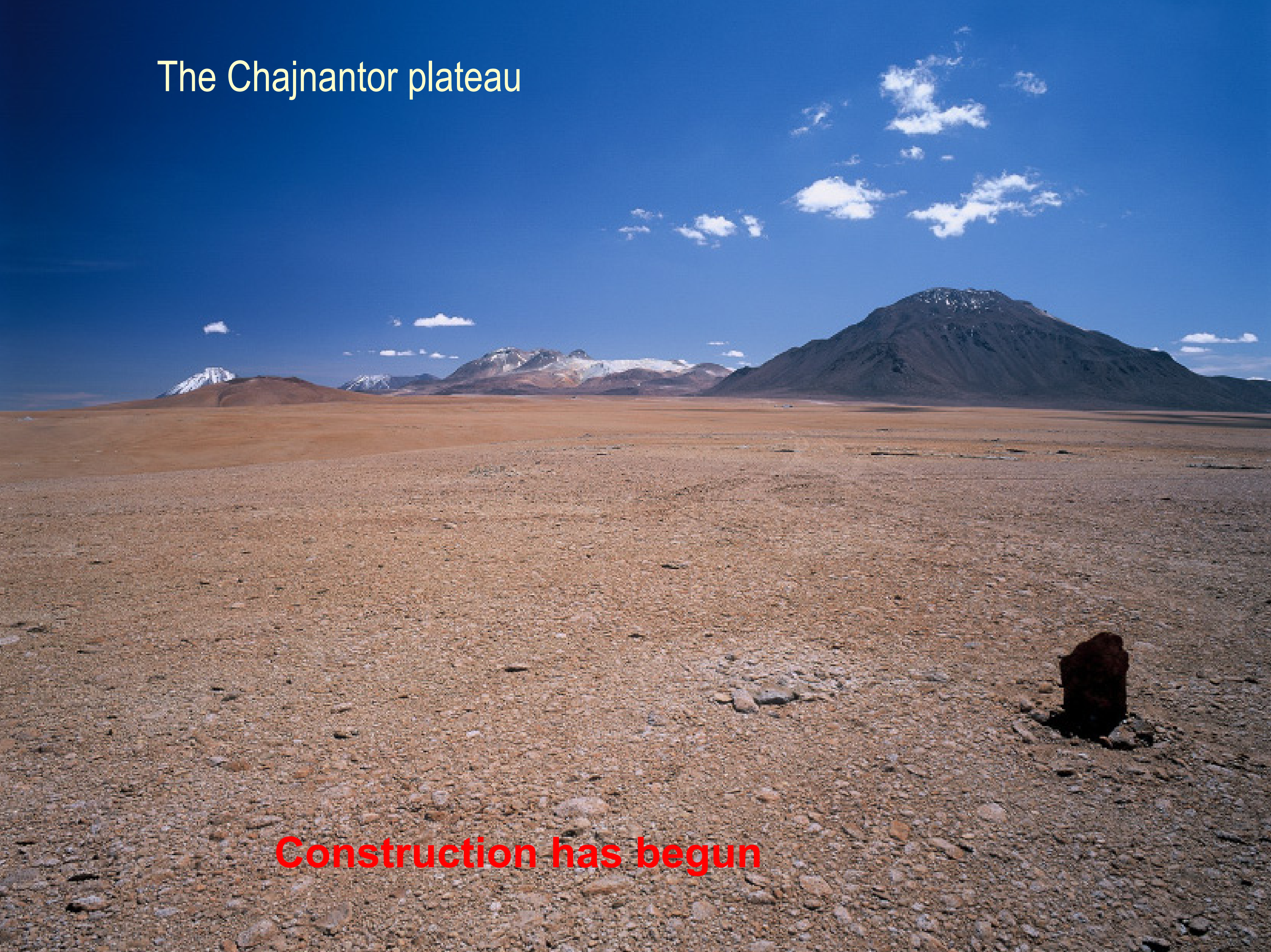
- Dual, linear polarization channels:
    - Increased sensitivity
    - Measurement of 4 Stokes parameters
- 183 GHz water vapour radiometer:
    - Used for atmospheric path length correction

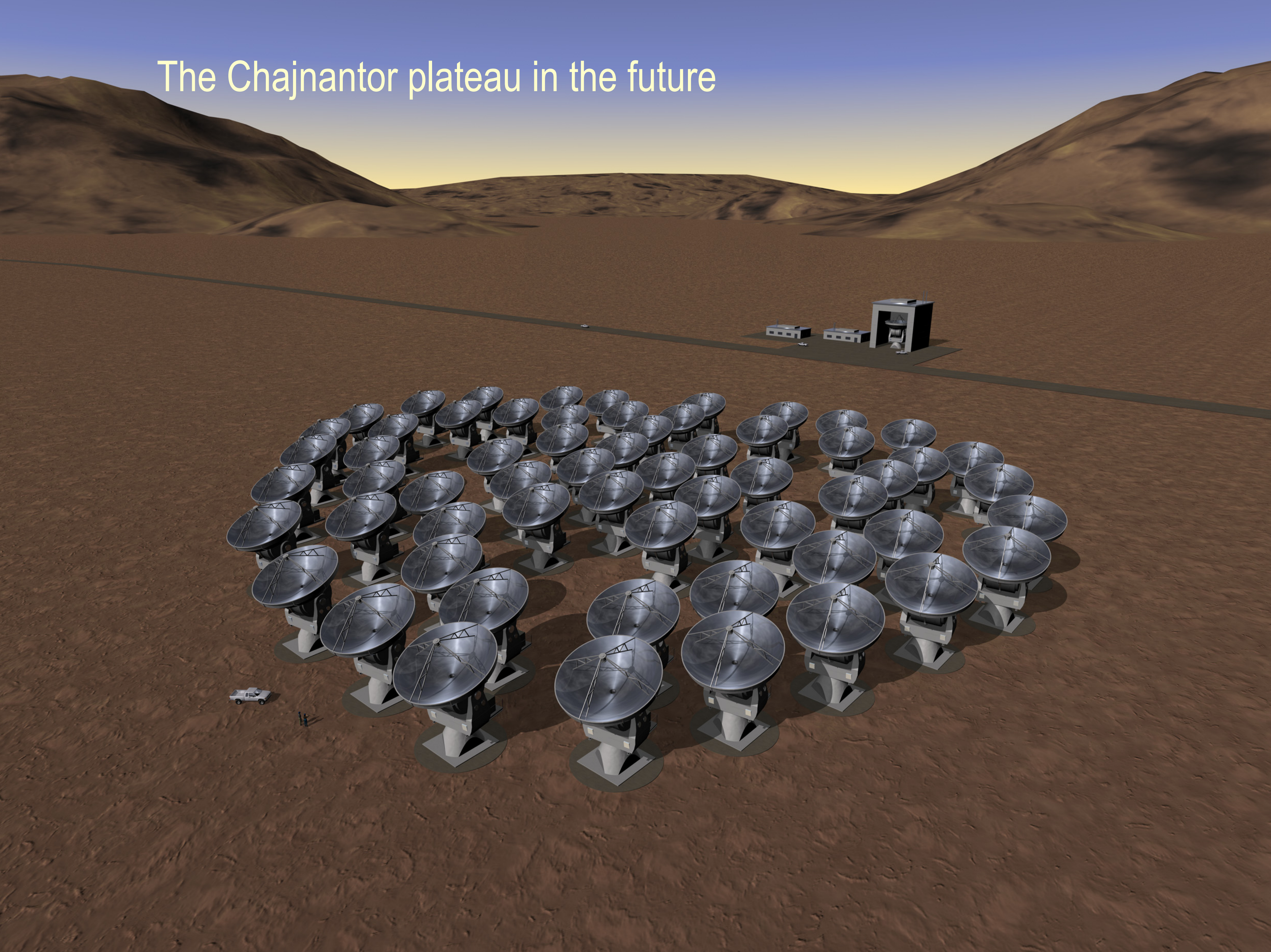
ALMA Prototype Antennas in Testing

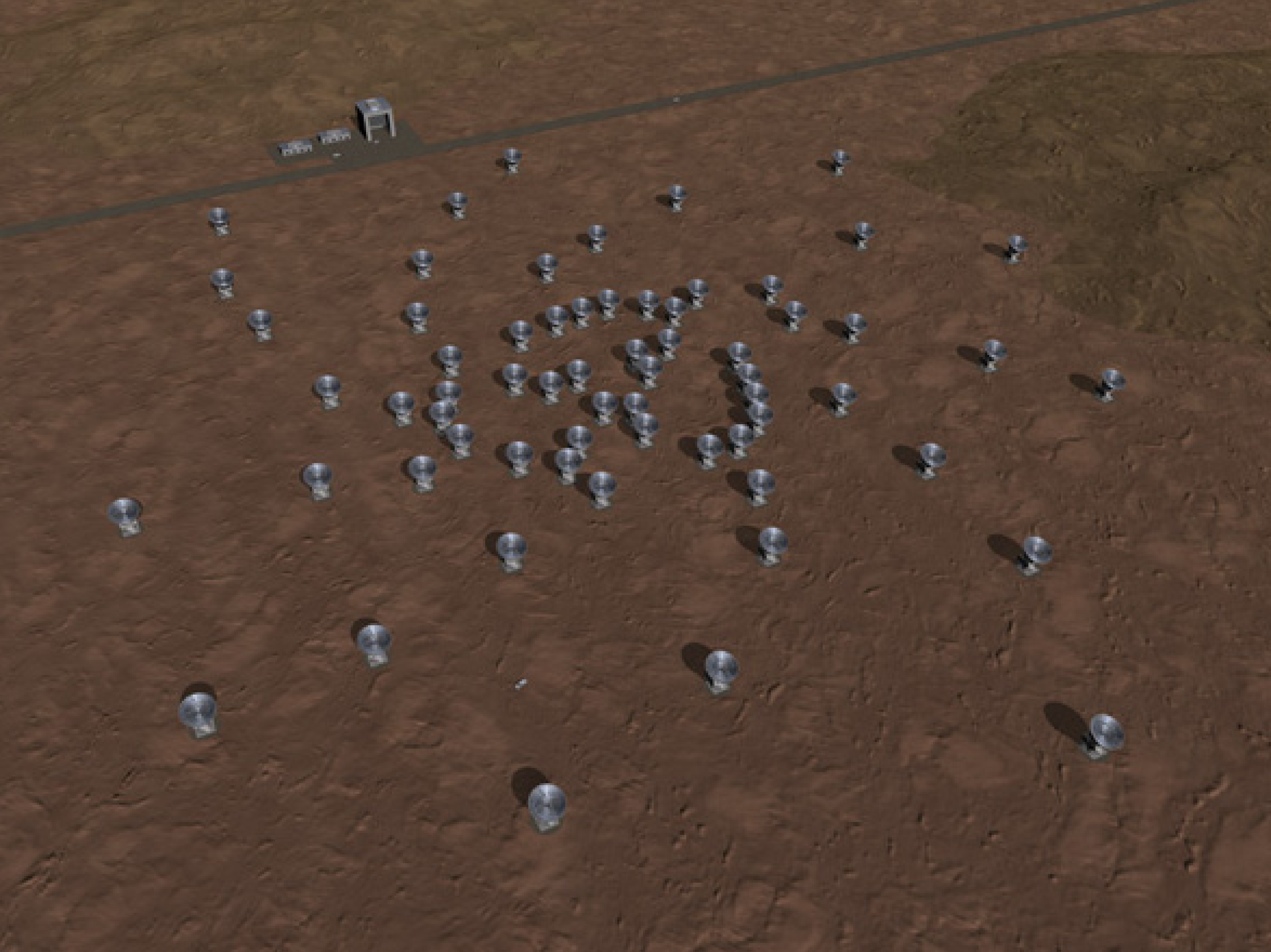
ALCATEL/EIE Prototype



VertexRSI Prototype


The Chajnantor plateau
Construction has begun


The Chajnantor plateau in the future



ALMA Median Sensitivity in 60 seconds

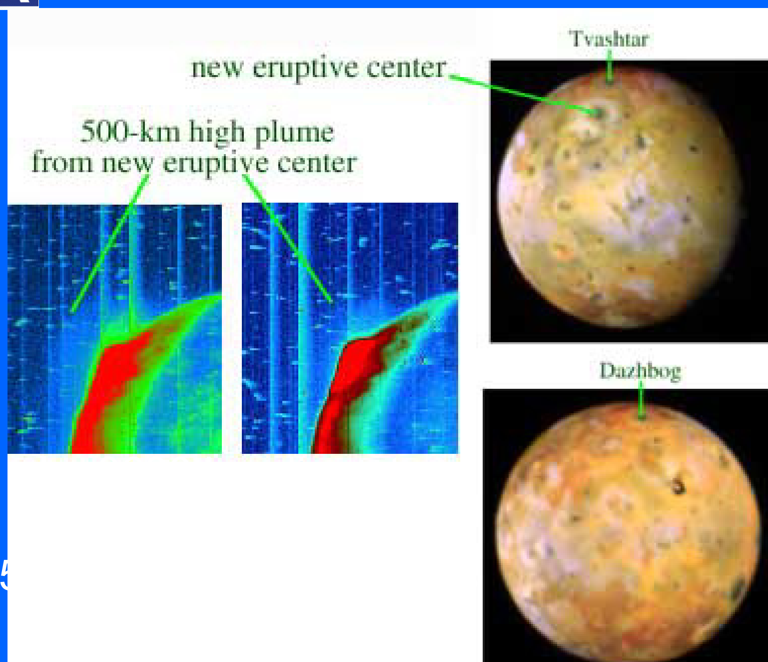
Point source sensitivity

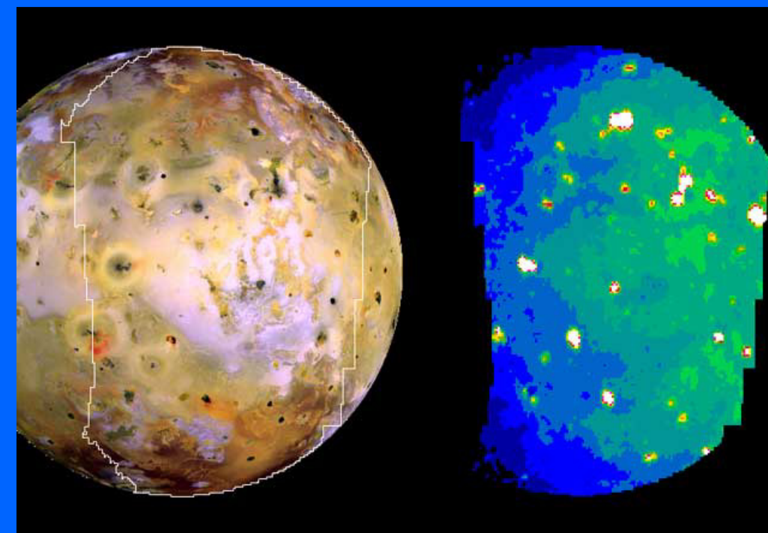
Frequency (GHz)	Continuum (mJy)	Line 1 km s^{-1} (mJy)	Line 25 km s^{-1} (mJy)
110	0.05	7.0	1.4
230	0.10	10.	2.1
345	0.2	16.	3.3
675	1.0	61.	12.

Brightness Temperature 1” beam

Frequency (GHz)	Continuum (K)	Line 1 km s^{-1} (K)	Line 25 km s^{-1} (K)
110	0.005	0.70	0.14
230	0.002	0.24	0.5
345	0.002	0.18	0.03
675	0.003	0.17	0.03

Planetary Atmospheres and Surfaces - Io's Volcanism

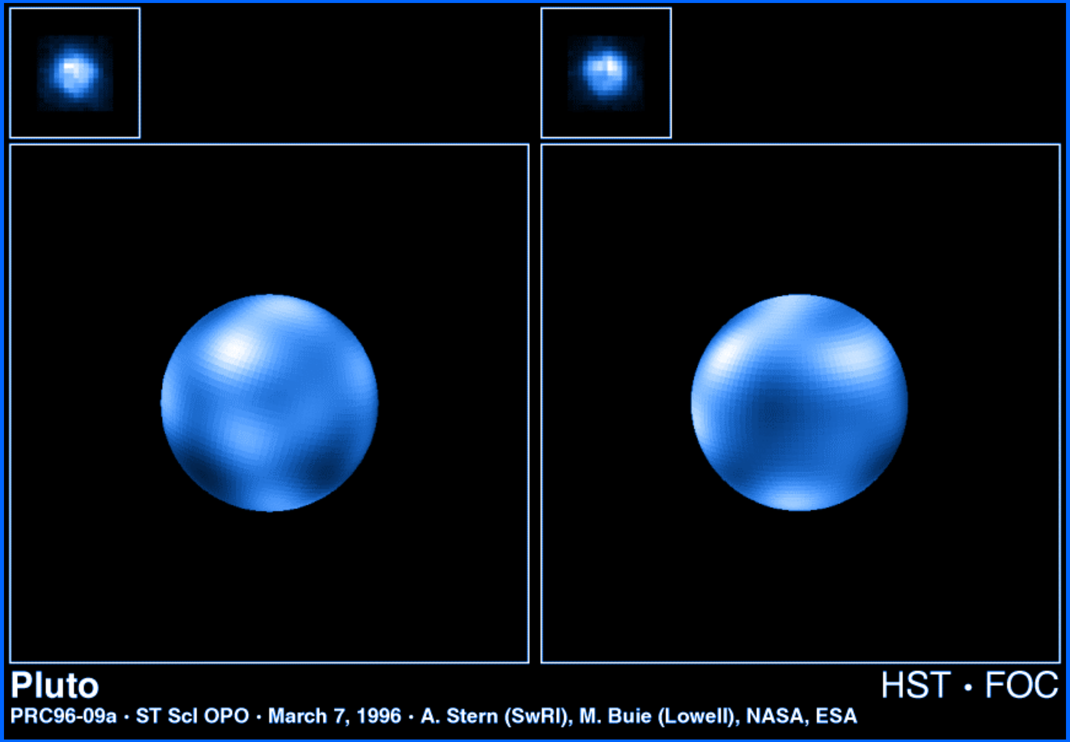




Galileo images courtesy NASA/JPL-Caltech

ALMA can map thermal emission from the surface showing location and temperature of hot spots, and can map molecules in volcanic plumes

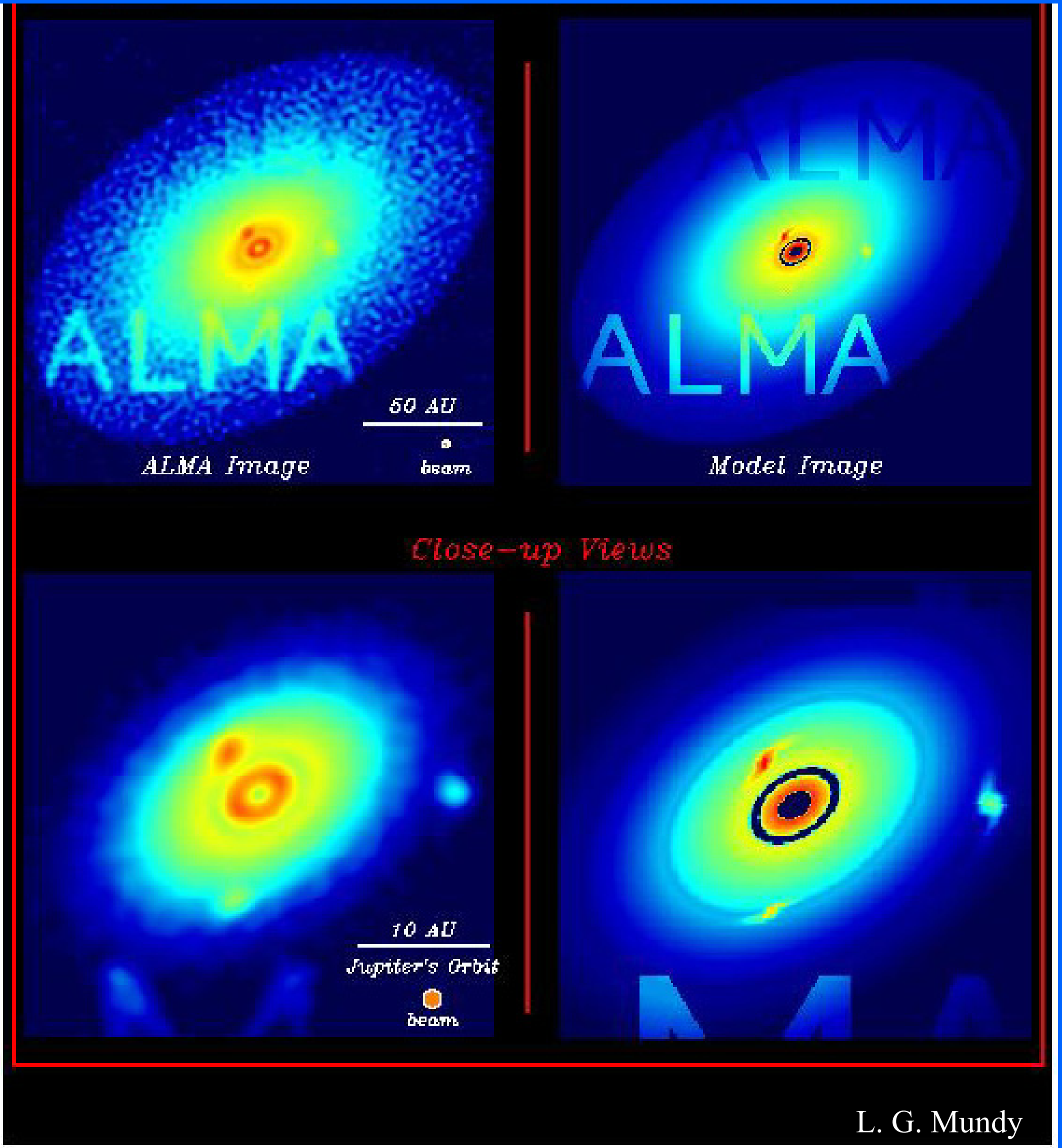
Planetary Surfaces -
Mapping Pluto and Charon



Pluto is 100 mas and Charon is 50 mas at current distance from sun.

ALMA will map the thermal emission from Pluto and Charon with up to 40 resolution elements, measuring temperature and/or emissivity variations that may change with time

Circumstellar Disks and Early Planet Formation



Observed Model

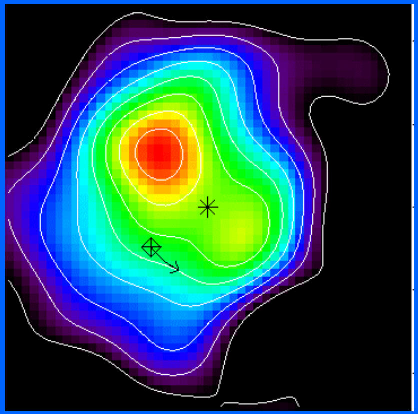
Simulation Contains:
* 140 AU, 0.01 solar mass disk
* inner hole (3 AU)
* gap 6-8 AU
* forming giant planets at:
  9, 22, 46 AU with local
  over-densities
* ALMA with 2x over-density
* ALMA with 20% under-density
* Each letter 4 AU wide, 35 AU high

Observed with 10 km array at 140 pc, 1.3 mm

ALMA can detect an 0.001 solar mass circumstellar disk in Orion in 60 seconds in dust emission.

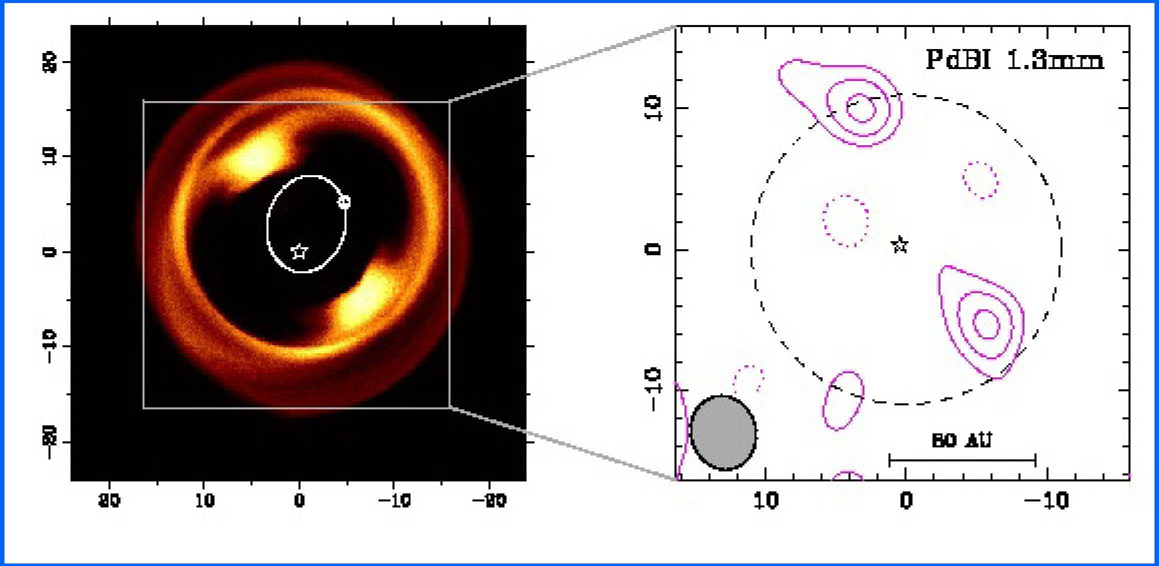
ALMA can map disks at 0.1” resolution with 0.01K continuum and 1 K line sensitivity at 345 GHz

Planets and Debris Disks



SMM image of Vega (JCMT by Holland et al.) at 850 microns with 15” resolution

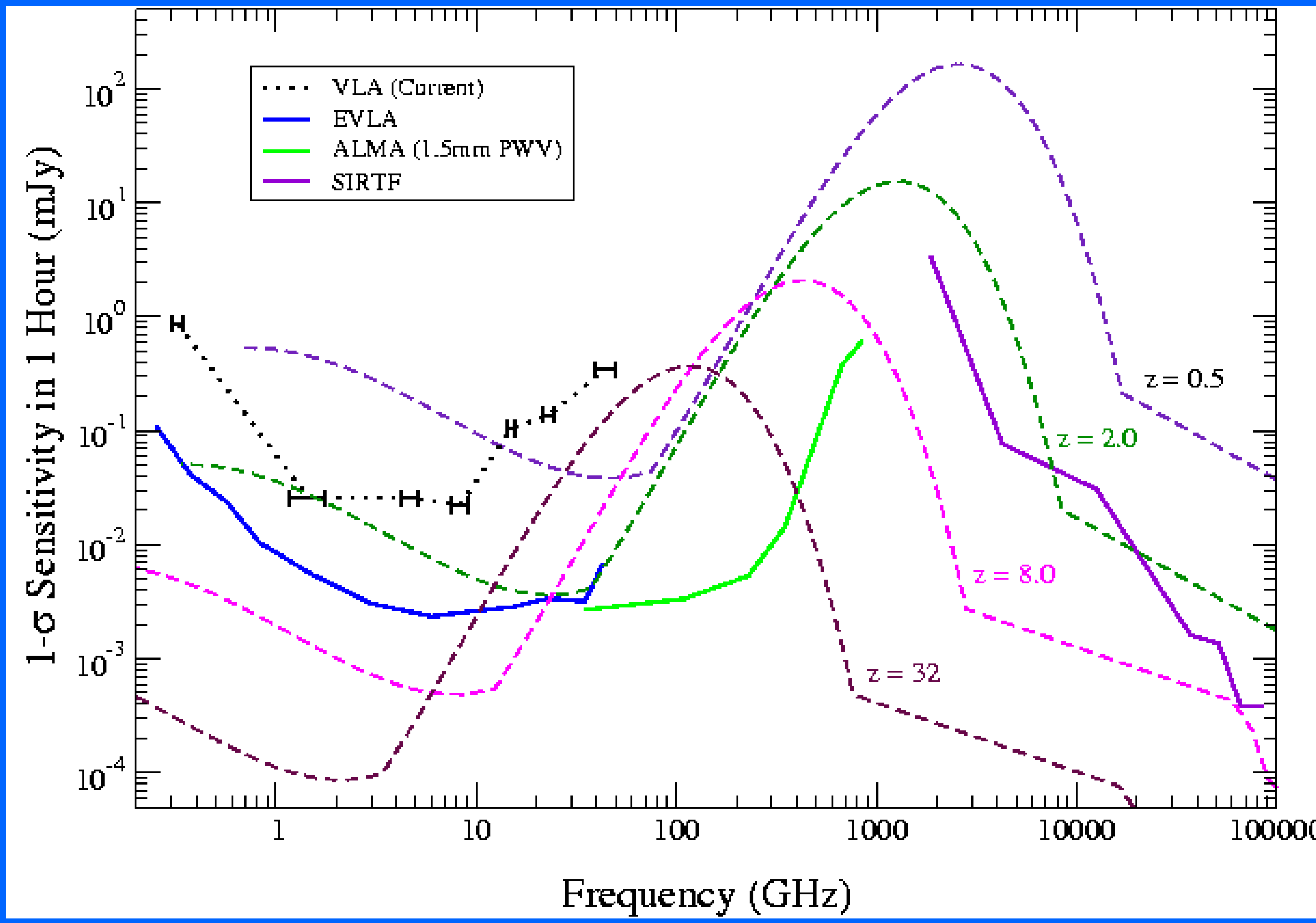
Model by (Wyatt 2003) as star, Neptune-like planet, and debris disk



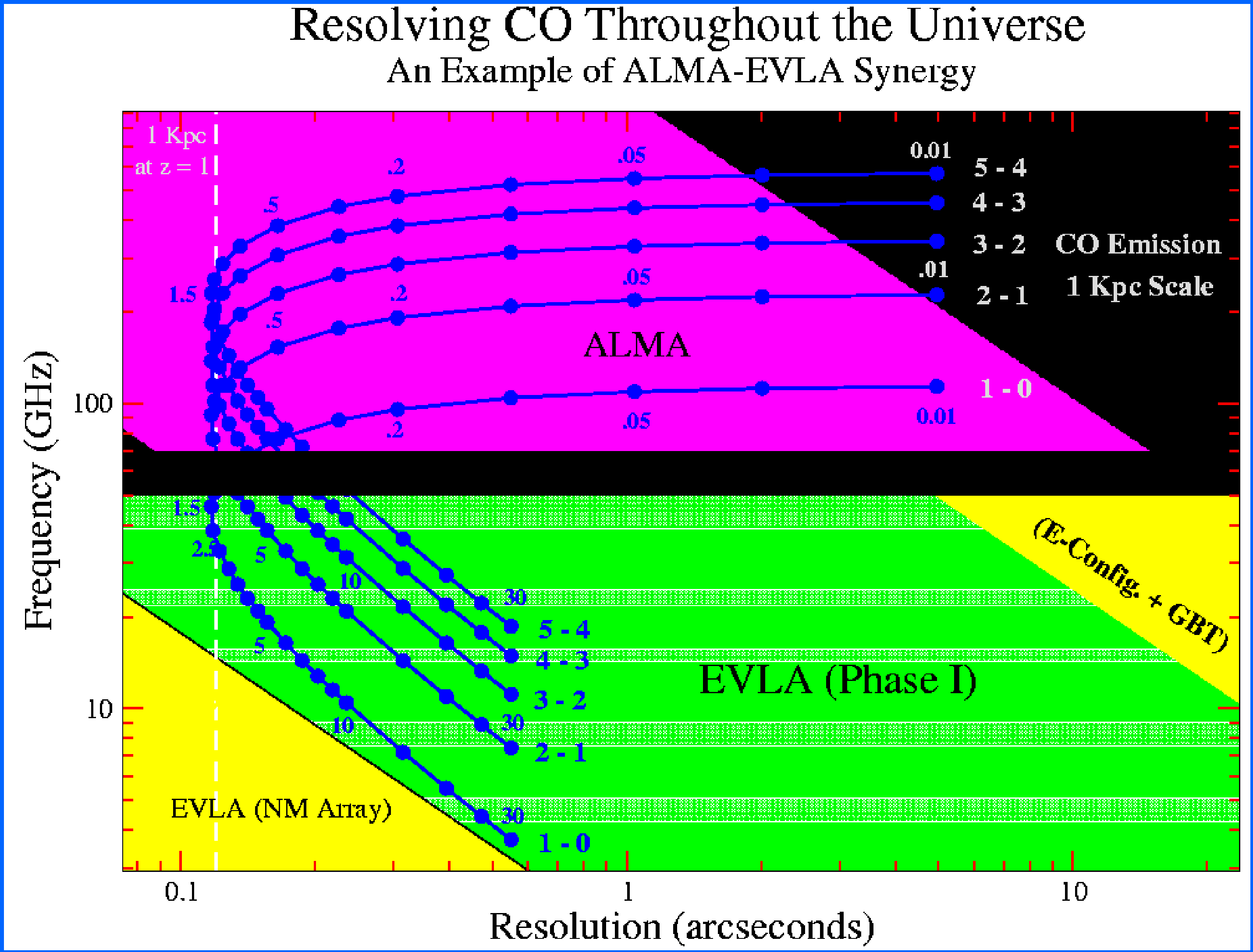
Vega at 1300 microns with 5” resolution (Wilner et al. 2003). Model of resonance with planet.

ALMA can detect the Vega disk in a few seconds and will have the sensitivity to map the emission at better than 0.5” resolution.

Detecting Dust Emission from Galaxies as all Z's

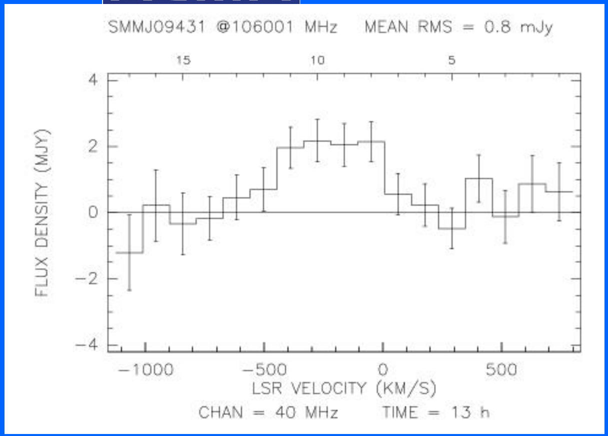


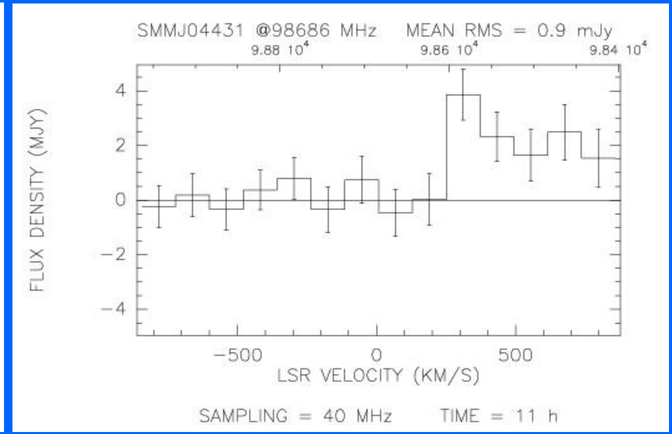
ALMA will detect large numbers of galaxies at all Z, beating the confusion limit

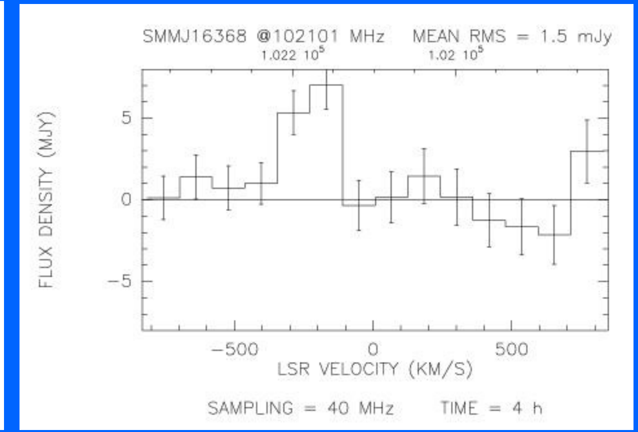


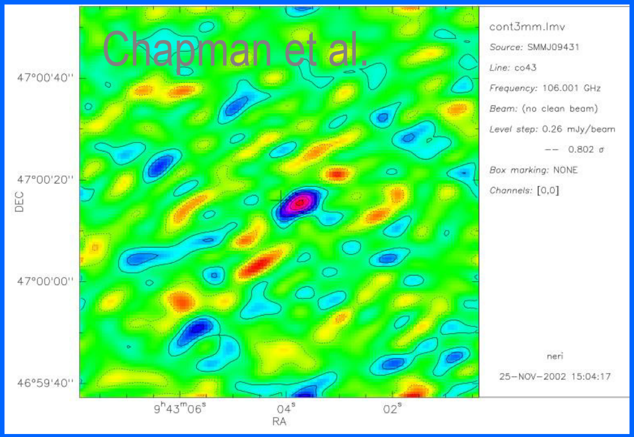
ALMA will probe dust and molecular gas emission during the period of most active galaxy formation, z=2-4

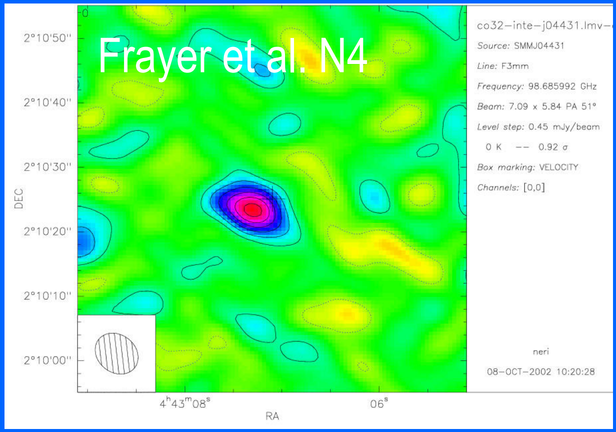
Submm galaxies in CO(3-2),(4-3)

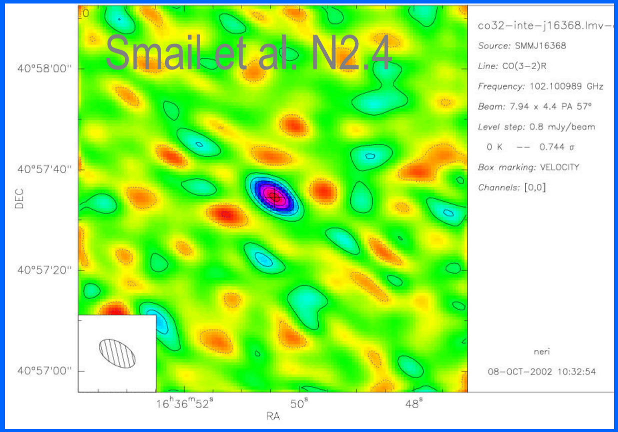








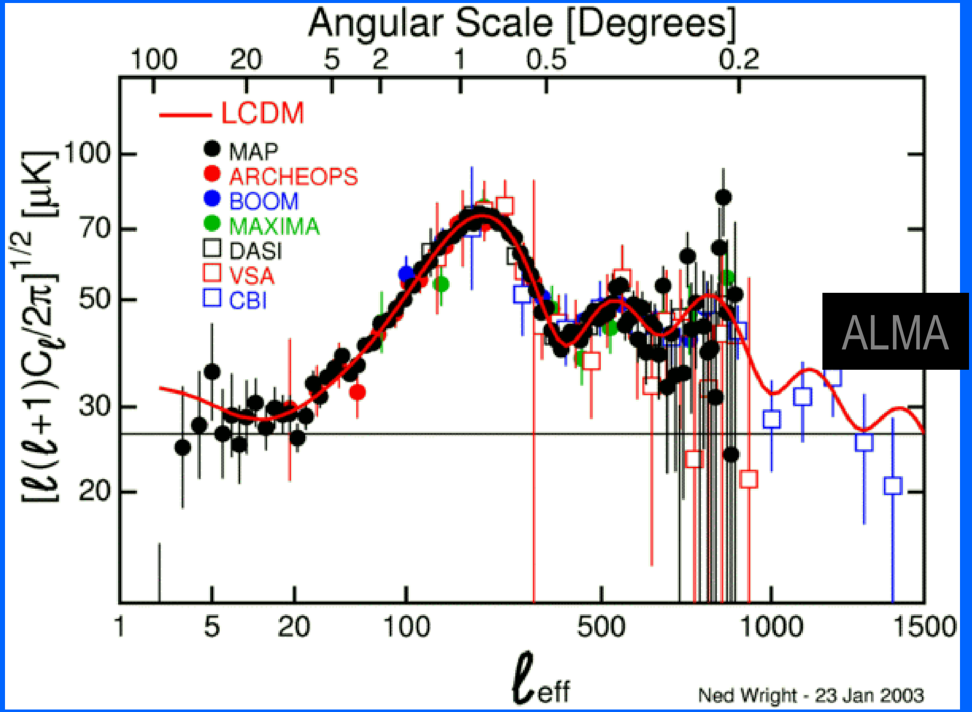


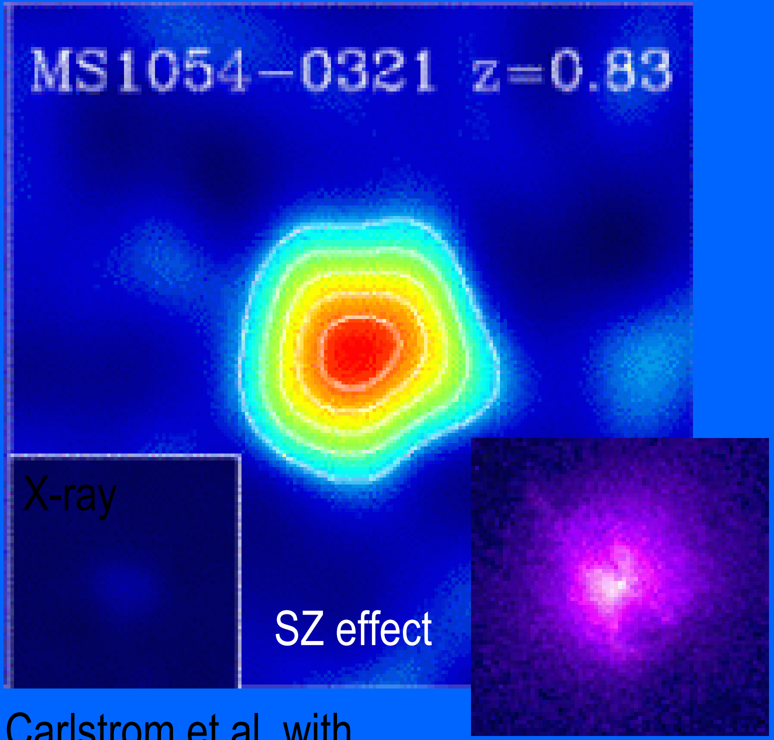


ALMA's spatially and spectrally resolved images will reveal the masses and dynamics during galaxy assembly

Fine angular scale CMB and SZ

ALMA compact array will be extremely sensitive to arcmin-scale CMB power from clusters, filaments and primordial fluctuations





Carlstrom et al. with arcmin resolution

Chandra – low-z Hydra cluster with substructure

Fine resolution will reveal structure in the intracluster medium to resolve physical conditions in cluster gas

ALMA Schedule

1998 – 2002 Design and Development

2003 Bilateral Agreement between NSF and ESO signed

2003Completion of Proto-type Antennas

2004 Ground Breaking

2004 Site construction, antenna contract awarded

2004 Japan joins

2005 First production antenna in Chile

2007 Q3 Early science operation begins, 8 antennas

2011 End construction

2012 Full science operations

ALMA 2012